RURAL WATER SUPPLY

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Rural Water Supply

A PRACTICAL HANDBOOK

ON THE

SUPPLY OF WATER AND CONSTRUCTION
OF WATERWORKS FOR SMALL
COUNTRY DISTRICTS

BY

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PREFACE BY G. C. GREENWELL,

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ONE of the greatest necessities of human life is an ample supply of wholesome water; and few objects are occasionally more difficult of attainment, not so much on account of any approach to impracticability as of certain hindrances to the mode of setting about it.

The situation of individuals with respect to each other renders that combination of the constituent parts of society, which is necessary in order to bring about a general co-operation, very difficult to adjust.

The supply of water enjoyed by one portion of the community may be sufficient both in quantity and in quality for all of its requirements; but the less happily circumstanced remainder may be dangerously near want. On the one hand, water is demanded, even though at the *cost* of the whole community; while on the other, such compulsion appears to be extremely unjust.

We are thus, at the very outset of the question of coercive water supply, met by antagonisms, which most certainly have not as yet been reconciled, with the result that many desirable schemes have either been quashed in their incipience, or, if completed under pressure, have given rise to heartburnings which have been productive of anything but peace and goodwill.

This early stage of the proceedings is, however, in the

present work supposed to have been passed over: the "tempest in the teapot" has exhausted itself, the strong will has prevailed, and the weak has gone to the wall as usual; the powers necessary to establish the waterworks have been obtained, and to direct in plain language how the precious element is to be brought from its hidden spring or other sources for the good of the population of the rural districts is the object of this little work.

There are various treatises, such as those by Messrs. Humber, Burton, Turner and Brightmore, and Fanning, as well as innumerable papers, which admirably deal with the questions of Water Engineering; but most, if not all of these, are of a more or less elaborate character; and it appeared to the writers that an elementary work on the subject was much to be desired—such as should enable the student to acquire a knowledge of the principles and construction of waterworks, simple in detail and efficient in application; which would qualify him to arrange and complete a system of waterworks on a moderate and effective scale—due qualification in which respect would lay the foundation for the future mastery of more important schemes.

The Authors have endeavoured constantly to keep in view, so far as lay in their power, simplicity of expression and of formulæ, in the hope of producing such a book as should be readable and intelligible by every one who earnestly desires to step on the lower rung of the ladder with the determination to climb gradually to the top.

G. C. GREENWELL.

DUFFIELD, NEAR DERBY,
May, 1895.

AUTHORS' PREFACE.

THIS little contribution to the literature of Waterworks Engineering is based upon a series of articles which appeared in the "Student's Column" of the *Builder*, from July to December, 1894, the articles having since been revised and brought up to date.

The Authors desire to express their grateful acknowledgment for the valuable information which they have obtained from the many standard works referred to in the text.

A. G.

W. T. C.

LONDON,
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CHAPTER I.

PRELIMINARY.

THE benefit of a plentiful supply of wholesome water in the country is hardly to be overestimated. Until recent years general systems of supply were almost entirely confined to towns, and, except in a few cases, where liberal-minded landowners carried out gravitation, or even small pumping schemes for the supply of water to their estates, rural populations were largely dependent upon open streams and shallow wells, which are always liable to pollution. The necessity for a proper supply of water to towns and congested populations generally is evident to all; but the idea that there should be any difficulty in procuring potable water in the country would seem incredible to most people who had not made rural life more or less of a study. The matter, however, rises to great importance when we remember that country areas are the source of supply of most of the food which is consumed in towns; and that when, for instance, a farm supplies milk for sale, any evil conditions under which that milk is produced follow it; and an impure water supply at a farm is frequently the cause of an outbreak of typhoid fever amongst the consumers of the milk at a distance.

A great change has, however, recently taken place, and

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schemes of rural water supply, especially in the Midlands, have become as plentiful as blackberries. This is partly attributable to the advance in sanitary knowledge, and to the necessities of rural populations becoming daily more pressing.

Sources liable to pollution tend to become more polluted, and pollution, generally speaking, is cumulative. The recent exceptionally dry seasons have brought to light distressing cases of privation, and one exposure has led to others.

The Local Government Act, 1888, has enabled County Councils to put considerable pressure upon local authorities, when they are of opinon, on the report of their Medical Officer of Health, that such authorities are not properly performing their duties under the Public Health Acts, one of which is to provide efficient water supplies for their districts.

The Local Government Act, 1894 (commonly known as the Parish Councils Act), includes two sections, which will probably facilitate the provision of many rural water supplies, which have hitherto appeared impracticable.

Sec. 8 gives power to a parish council "to utilize any well, spring, or stream within their parish, and providing facilities for obtaining water therefrom, but so as not to interfere with the rights of any corporation or person."

Sec. 16 provides that where a parish council resolve that a rural district council ought to have provided the parish with a supply of water "in cases where danger arises to the health of the inhabitants from the insufficiency or unwholesomeness of the existing supply of water" (Public Health Act, 1875, sec. 299), complaint may be made to the County Council, which may transfer those duties to itself, or may appoint a person to perform the duty.

There are very important differences between urban and rural water supply, which often make the difficulties to be contended with much greater in the latter than in the former. Except where the scheme is carried out by private individuals for the benefit of their estates, the duty of providing

an efficient water supply usually devolves upon the local authority.

By the Public Health Act, 1875, sec. 299, it becomes the duty of a Local Authority to provide their district with a supply of water, "in cases where danger arises to the health of the inhabitants from the insufficiency or unwholesomeness of the existing supply of water, and a proper supply can be got at a reasonable cost." The money for carrying out such a supply is usually obtained on loan (after a Local Government Board inquiry), repayable by yearly or half-yearly instalments of principal and interest in thirty years. The present rate of interest is usually three and a half per cent. per annum, which makes the annual instalment £5 8*s.* 9*d.* per cent.

This annual charge, together with the working expenses, has to be met either by a water-rate over the whole area, or by charges made upon the consumers, or by both. In an urban district, where nearly the whole population benefits by the supply, a water-rate is not necessarily a hardship; but in rural districts, where the area is determined by parish boundaries, and only a small portion of the population benefits by the supply, the case is different. As a consequence of the shuffling which frequently becomes possible through the intricacies of the law upon the subject, the few are sometimes benefited at the expense of the many.

A small village had a fairly good water supply, but it included a patch of elevated ground excellently suited for building sites, but where water was conspicuous by its absence. Largely through the instrumentality of a local architect, himself a leading member of the local sanitary authority, this patch of ground was covered with houses of the villa class, in spite of section 6 of the Public Health (Water) Amendment Act, 1878, which makes it unlawful in any rural district for the owner of any dwelling-house which may be erected or rebuilt after the passing of this Act, to occupy or permit the same to be occupied without first obtaining the certificate of the sanitary authority, "that there is provided, within a reasonable distance of the house,

such an available supply of wholesome water as may appear to such authority to be sufficient for the consumption and use for domestic purposes of the inmates of the house."

The houses being built and occupied, it became necessary to provide them with water; so a scheme was approved and carried out by the Local Sanitary Authority. To meet the expenditure attendant upon the first cost of the scheme, for obvious reasons, a water-rate was made over the whole parish, instead of a charge being made on the consumers only. One of the inhabitants of the village, who resided upon his own property, had, previous to the above events, expended over a hundred pounds in order to efficiently supply his house with water from an excellent, never-failing well upon his premises. Notwithstanding that this supply had been pronounced of exceptional purity by competent analysts, this unfortunate owner was compelled to contribute some £5 a year for a commodity which he in no way required. It is needless to observe that this individual was not the only sufferer.

In certain cases the Local Government Board will consent to a special district being constituted, excluding as far as possible such areas as will not receive or do not require a supply. The Local Government Board, however, are rarely in favour of this step for purposes of water supply alone. The only alternative, therefore, is to make a charge upon the consumers sufficient to cover the periodical instalments of principal and interest, as well as the working expenses of the scheme.

The maximum charge which may lawfully be made (except under special circumstances) where a house is without a proper supply of water, and where a supply is enforced by a local authority, is 2*d.* a week per house, or 8*s.* 8*d.* a year. Where, however, the supply is given by agreement, the authority may make such reasonable charge as they think fit. Where the rate is levied upon the consumers only, it must be so adjusted as not to produce a profit which would benefit the ratepayers at large at the expense of the consumers.

A usual charge is 2*d.* per week for houses with a rateable value under ten pounds per annum, and 5 per cent. per annum when the rateable value exceeds that amount. This scale averages 5 per cent. per annum throughout.

If the annual instalment of principal and interest, together with the working expenses, does not exceed 5 per cent. on the rateable value of the property supplied, the scheme can be made self-supporting, as the remainder of the parish or parishes, receiving no benefit from the supply, need not be made to contribute. If, however, the expenditure exceeds the receipts, the balance must be met by a special water-rate levied over the whole area, irrespective of benefit.

As the rateable value of rural is considerably less than that of urban districts, area for area, and as the length of pipe necessary for the supply of a given number of houses is many times greater, the first cost of a water supply scheme for a rural area must of necessity be made relatively small and the working expenses reduced to a minimum. To secure this end gravitation schemes are usually the only means which can be entertained, as the 5 per cent. above-mentioned rarely allows a sufficient margin for the working expenses of a pumping establishment. Occasionally a self-acting pumping system becomes possible where a fall of water can be utilized to work a water-wheel, turbine, or hydraulic ram.

In the following pages, it is proposed to deal with such schemes as are usually feasible in rural districts, taking the above remarks into consideration. The various systems for affording such supplies will be described in detail, the principles explained, the machinery and materials carefully described, and the necessary information supplied both for preparing and carrying out the schemes. Plans, sections, specifications, and estimates of cost will be given, and, where possible, detailed prices of materials and workmanship will be indicated.

CHAPTER II.

VARIOUS METHODS OF SUPPLY. ADVANTAGES AND DISADVANTAGES OF EACH.

The selection of a source from which to obtain a water supply for a rural district, is dependent on a variety of considerations, among which are the following:—

1. Purity of the supply.
2. Volume and permanency.
3. Elevation with regard to the district to be supplied.
4. Distance from the district to be supplied.
5. Nature of intervening ground.
6. Purchase of water rights and easements.

In the "Suggestions as to Water Supply," etc., issued by the Local Government Board, the various sources from which water is usually obtained for purposes of domestic supply are arranged as follows:—

From mountain ranges, which act as condensers.
From rivers and streams.
From natural springs.
From wells artificially formed.
From impounding reservoirs.
From a combination of two or more of these sources.

Impurities likely to be met with in a source of water supply are of two kinds—

1. Those that can be removed by inexpensive means —*e.g.* mechanical filtration.

2. Those which cannot be thus removed, or in the removal of which heavy expense would be incurred.

In the former class are included organic matter of vegetable origin in suspension—*e.g.* peat, also non-poisonous mineral substances, such as carbonate of lime.

In the latter class are included the products of decaying organic matter of animal origin, as well as actual organic life, or what is generally known as sewage contamination; also poisonous substances, such as lead, and other substances, such as common salt (NaCl) which becomes injurious when present in large quantities.

Undoubtedly the first necessity of a water supply for domestic purposes is purity, and this must be assured at the outset.

In taking samples of water for purposes of analysis, a perfectly clean stoppered Winchester quart bottle (holding about half a gallon) should be used. The bottle should have been previously washed out with a little strong sulphuric (H_2SO_4) or hydrochloric (HCl) acid, and then rinsed with frequent changes of pure water until the rinsings do not redden a piece of blue litmus paper. Before taking the sample, the bottle and the stopper should be thoroughly rinsed with the water to be analyzed, and should then be filled to the neck with the water, stoppered, sealed, and labelled on the spot, and, if possible, analyzed within forty-eight hours.

In submitting a sample of water for analysis, as much information as possible should be given as to the situation of the source from which it has been taken, both geologically and with regard to any possible causes of pollutions in the vicinity. It is only by reading the analysis of a sample of water in close conjunction with the most careful observation of the surroundings and conditions of the source from which it has been taken, that any reliable opinion can be formed as to the suitability or otherwise of the supply for domestic purposes.

The River Pollution Commissioners, in their sixth report, classified the various sources with regard to potability as follows:

Wholesome	1. Spring water.	Very palatable.
	2. Deep well water.	
	3. Upland surface water.	Moderately palatable.
Suspicious	4. Stored rainwater.	
	5. Surface water from cultivated land.	Palatable.
Dangerous	6. River water to which sewage gains access.	
	7. Shallow well water.	

Rainfall is, practically speaking, the ultimate source of all water supply, and the nearer the source the purer, though not necessarily the more palatable, the water. Rainfall is disposed of in three ways:—

1. A portion is again evaporated.

2. Another portion flows over the surface of the ground to form streams and rivers.

3. The remainder sinks into the ground, and forms the underground reservoirs in which wells are sunk, issuing again at the lowest lip as springs.

1. *Spring water.*

The water from deep-seated springs is usually organically pure, though frequently highly charged with mineral substances. Where, however, the outcrop of the water-bearing stratum, at the point where it yields the spring, is of large area, and upon it houses, farmyards, and other possible sources of pollution are in existence, great care should be taken that the spring is not thereby affected.

A spring rises on the side of a hill at the junction of the upper green sand with the Oxford clay. A farmhouse is situated about 150 yards distant from the spring, and 100 feet above it, on the outcrop of the upper green sand. A sample of water from the spring was submitted to the county analyst for examination, and the following is an extract from his report thereon:—

"This water is plainly contaminated with the products of decomposition of animal matter, and is liable, as has been the case in several recorded instances, to carry the infective matter of specific disease. A consideration of the facts of

the case confirms me in this opinion, and the amount of pollution is greater than at first sight appears, because the green sand furnishes a water of more than average purity: probably about one-half the solid matter of this water is directly derived from the farm sewage."

The intervening land between the farmyard and the spring is grass pasture, and there is no other discoverable source of pollution.

2. *Deep well water.*

Deep wells, especially those sunk through an impervious bed of considerable area, afford supplies of excellent quality. Care must be taken that the portion of the well above the impervious bed is so constructed as to prevent percolation from the surface or from the upper strata.

3. *Upland surface water.*

Water from this source is usually satisfactory, but is frequently discoloured with peat, even to such an extent as to render it unfit for domestic purposes.

4. *Stored rain water.*

Where there is no other available source, and there is freedom from smoke, etc., rain water may be used for domestic purposes, but it is unpalatable on account of the absence of aëration. It should be filtered before storage, and the tank should be well ventilated.

The three remaining sources are not fitted for domestic purposes. River water is, however, frequently used, but it requires efficient filtration, which renders it too expensive for use on a small scale.

The next points for consideration are the volume and permanency of the source. To obtain this information frequent gaugings, taken over a considerable period, are necessary. The area of the watershed relied upon, the greatest and least rainfall, percolation, and evaporation are all important factors of the result. These points will be considered in a future chapter. Information from the oldest inhabitants of the locality must not be allowed too much weight, or serious consequences may result.

In a recent survey for a village water supply, three

apparently deep-seated springs of most excellent quality were found in close proximity to each other. These springs were gauged on the 21st of March, 1893, and yielded a total volume of 820 gallons per minute. On April 8th they had fallen to 436 gallons per minute, and on May 6th to 207 gallons per minute. In June they were dry.

In the course of the same survey a spring was brought under notice, as to the permanency of which opinions were somewhat conflicting. Reference was made to the "oldest inhabitants," three nonogenarian labourers, who stated that they had known the spring all their lives, and that it had never yielded less than a certain flow. This was in February, 1893, and shortly after the spring failed.

The elevation of the source with regard to the district to be supplied is of great importance, for upon this will depend whether the natural flow of water by gravitation can be utilized, or whether pumping must be brought into requisition. Especially for a rural supply, gravitation should be secured if possible; for although the outlay is generally much greater, a heavy annual cost is avoided. Occasionally, where a sufficient quantity and fall of water are available, water-wheels, turbines, and hydraulic rams, which require no fuel and little attention, may be used; and in exposed situations, windmills are sometimes employed for pumping water on a small scale.

In deciding upon the relative merits of a gravitation and a pumping scheme, the distance of the source from the district to be supplied forms an important element; for if the distance over which the water has to be carried, in the former case, is great and the fall slight, pipes of large diameter may be required, entailing considerable expense, while in the latter case the length of pipe may be inconsiderable.

Especially in a gravitation scheme, on account of the relatively great distance over which the supply has usually to be carried, the question of easements is of great importance; whilst the question of water-rights affects both gravitation and pumping schemes to much the same extent.

These claims frequently lead to so great an expense as to necessitate the total abandonment of a water-supply scheme.

Every detail affecting these points should be carefully ascertained before any scheme is fully considered, and agreements *in writing* should be entered into with all parties in any way interested before works are commenced.

In a recent water-supply scheme, a claim was overlooked which might have been easily settled for £5. In consequence of this omission a trial took place four years later, costing the authority who carried out the scheme over £600.

CHAPTER III.

LAND VALUATION, RIPARIAN RIGHTS, EASEMENTS, AND COMPENSATION.

THE persons carrying out a water scheme are technically known as the "undertakers," and may be classified as follows :—

1. Private individuals or companies not possessing statutory or parliamentary powers.

2. Companies who have obtained a Provisional Order under the Gas and Water Facilities Acts, or the fuller powers of a private Act of Parliament.

3. Local Authorities, urban or rural, acting under

(*a*) The Public Health Acts;

(*b*) A Provisional Order;

(*c*) A Private Act of Parliament.

Private individuals or companies not possessing statutory or parliamentary powers are placed at a great disadvantage. They are liable to indictment or injunction for breaking up or obstructing the highways; they cannot acquire water or land, except by agreement; they cannot levy rates or make charges, except by agreement; and the only advantage which they can claim is that they "cannot be compelled to furnish a supply of water to any one on any terms."

It is obvious that, except where a landowner carries out a system of water supply for the benefit of his property, and where no difficulties arise as regards water-rights, easements, etc., or obstructive highway authorities, further powers are generally necessary.

The simplest and most economical way in which to obtain

such powers is, to obtain a Provisional Order under the Gas and Water Facilities Act, 1870, which must afterwards be confirmed by Parliament. A Provisional Order can only be obtained with the consent of the Local Sanitary Authority, and provided that there is not already in existence any legally empowered water company, able and willing to afford the necessary supply.

A Provisional Order (except in the case of a Local Sanitary Authority) does not confer compulsory powers as to purchase of land or water, or as to entry upon premises. To obtain these powers a special Act of Parliament is necessary.

The powers conferred by a special Act are very comprehensive, and are plainly set forth in the introduction to "The Law Relating to Gas and Water," by Messrs. Michael and Will, as follows:—

"Thus authorized by a special Act, a company may take compulsorily lands and streams, subject to the provisions and restrictions of the Lands Clauses Acts in exercising such powers. The undertakers must make to the owners and occupiers of, and all other parties interested in, any lands or streams taken or used for the purposes of the special Act, or injuriously affected by the construction or maintenance of the works thereby authorized, or otherwise by the execution of the powers thereby conferred, 'full compensation for the value of the lands and streams so taken or used, and for all damage sustained by such owners, occupiers, and other persons by reason of the exercise, as to such lands and streams, of the powers vested in the undertakers.' For the purpose of constructing waterworks, the undertakers may enter upon the lands and places described on the plans and in the books of reference, and may take the levels and set out the parts thereof, and dig and break up the soil, and trench and sough the same, and remove and use earth, stone, mines, minerals, trees, or other things. They may sink wells, make, maintain, alter, or discontinue reservoirs, waterworks, cisterns, tanks, aqueducts, drains, cuts, sluices, pipes, culverts, engines, and other works, and erect buildings; they may also divert and impound water from the streams

mentioned for that purpose in the special Act or the said plans or books of reference, and alter the course of such streams, not being navigable, and take such waters as may be found in and under, or on the lands to be taken for constructing the works. In the exercise of these powers, the undertakers are to do 'as little damage as can be.' With respect to the breaking up of streets for the purpose of laying pipes, the undertakers are empowered to open and break up the soil and pavement of the several streets and bridges within the limits of the special Act, and to open and break up sewers, drains, or tunnels, within or under the same, and to lay down pipes, conduits, service-pipes and other works and engines, and from time to time to repair, alter, or remove the same."

A Local Sanitary Authority (urban or rural) is placed in a somewhat different position to a company. Acting under the Public Health Act, 1875, a Local Sanitary Authority is invested with all the necessary powers for carrying out and afterwards maintaining a water-supply scheme, and in a pecuniary sense, is much better situated than a company, insomuch as it can compel the whole district to wholly or partially contribute the funds to meet the necessary expenditure, and is not restricted to the actual consumers of the water. Lands or easements necessary for any scheme of water supply must, however, be obtained by agreement; compulsory powers in this respect can only be secured by a Provisional Order or a special Act. A Local Authority having obtained a Provisional Order is, however, powerless, except by agreement, to purchase water-rights, *i.e.* the right to abstract water from streams, etc., and this difficulty can only be overcome by a special Act of Parliament.

A further difference existing between the powers of a local sanitary authority and those of a company, consists in the privilege which the former possesses of purchasing the easement only of laying pipes through land, whilst a landowner can compel a company to purchase the freehold of the land, except special provision has been made in the private Act.

As the supply of water to communities is in the majority of cases undertaken by the Local Sanitary Authority, the following pages will, unless otherwise stated, be specially adapted to assist in the preparation and execution of such schemes.

Sec. 308 of the Public Health Act, 1875, enacts as follows: "Where any person sustains any damage by reason of the exercise of any of the powers of this Act, in relation to any matter as to which he is not himself in default, full compensation shall be made to such person by the Local Authority exercising such powers; and any dispute as to the fact of damage or amount of compensation shall be settled by arbitration in manner provided by this Act, or if compensation claimed does not exceed the sum of twenty pounds, the same may, at the option of either party, be ascertained by, and recovered before, a court of summary jurisdiction."

Sec. 332 of the same Act further provides that: "Nothing in this Act shall be construed to authorize any Local Authority to injuriously affect any reservoir, canal, river, or stream, or the feeders thereof, or the supply, quality, or fall of water, contained in any reservoir, canal, river, stream, or in the feeders thereof, in cases where any body of persons or person would, if this Act had not passed, have been entitled by law to prevent or be relieved against the injuriously affecting such reservoir, canal, river, stream, feeders, or such supply, quality, or fall of water, unless the Local Authority first obtains the consent in writing of the body of persons or person so entitled as aforesaid."

These sections, taken together, indicate the importance attached to the purchase of and compensation for land and water rights, in connection with nearly every water-supply scheme. Unfortunately these matters are not regulated by recognized principles; but the following details, taken from actual experience, will act as a guide in most cases likely to occur in general practice.

In valuing property required for the construction of waterworks, the elements of value and interest to be

purchased are numerous, and vary according to the special circumstances of each case. The main points to be considered are: The value of the special adaptability of the site, of agricultural land, garden land, woods and plantations, houses and outbuildings, minerals, severance and injury, removal, trade and other fixtures, loss of trade profits, loss on forced sale.

Special Adaptability of the Site.

The "special adaptability" value has been brought into considerable prominence in waterworks cases during the last few years. This element of value was first urged in the case of Sir Walter Riddell and the Newcastle and Gateshead Water Company, and was afterwards an important feature in the case of the Countess Ossalinsky and the Corporation of Manchester, in reference to the Thirlmere scheme. These cases have been relied on as precedents in all the recent arbitrations under the Lands Clauses Act for waterworks purposes.

The valuation is made on the special adaptability of the land for reservoir or other purposes arising from the special and physical conditions of the property. Such value must not be based upon the value to the purchaser, but upon the value to the owner or seller.

In taking into consideration the special adaptability element, it is either taken as the whole value less the agricultural value, or in addition to the latter. In most cases, however, the agricultural value is excluded, and the property solely valued on its adaptability, to which must be added severance and other claims, if any. The value in such cases varies from £3 to £10 per acre, and at from twenty to twenty-eight years' purchase.

In the case of Riddell *v.* Newcastle and Gateshead Water Company, which went to the Court of Appeal, Lord Bramwell said as follows: "Special value in special circumstances should be adopted if you are dealing with reservoir sites, just as though you were dealing with building sites;

if you are wanting to buy land which is suitable for building purposes, you must pay building price for it."

Again, in the case of Ossalinsky *v.* Corporation of Manchester, the Court held, "if apart from the particular purchaser and the particular Act, land has enhanced value from any special circumstances, the owner is entitled to it." This case did not go to the Court of Appeal, the judgment being adopted by both parties.

Agricultural and Garden Land.

Freehold land is usually estimated on the nett annual rental, at from twenty-eight to thirty-five years' purchase.

Leasehold property is valued for the landlord on the rent and reversionary value, the tenants claiming the value of the unexpired term, with an allowance for forced sale and removal in proportion to the length of term.

The owner of a *reversion* is entitled to such a sum as would, if accumulated at interest until the date when the property will fall in, amount to the fee-simple value. The valuation is made on a basis of 3 per cent.

Woods and Plantations.

These are accurately measured for the acreage, and then arranged under the following heads:—

Full-grown timber.
Half-grown timber.
Young plantations.
Underwood.

Full-grown timber is in most cases measured, owing to the uncertainty of judging their value by the eye, allowance being made for bark and loss in cutting.

Half-grown timber is valued at an average price per acre, based upon the present age of the timber, and the time which will elapse before it will arrive at maturity. This period varies according to the situation, climate, and the nature of the trees.

Young plantations are valued on the outlay in producing them—viz. the plants, planting, fencing, draining, and other matters; and the rate of interest depending on the appearance and quality of the trees.

Underwoods are valued in a similar manner to half-grown timber.

The land occupied by the woods and plantations is estimated at the fee-simple value.

Houses and Outbuildings.

The value of these is estimated on the nett annual rental, less repairs, at twenty years' purchase, and an additional 10 per cent. for forced sale. Due regard must be paid, in making the valuation, to any prospective increase in the value of the property.

Minerals.

Minerals existing under lands to be valued, can only be properly estimated when such have been proved either on the land to be valued or on some adjoining property. The valuation is based upon the annual rental at from ten to sixteen years' purchase.

Severance and Injury.

When a portion only of a property is required by the undertakers, the remaining portion is frequently diminished in value, or even rendered practically useless, for sheep or stock farming or other purposes, owing to the want of shelter, water, accessibility, etc. These disadvantages must be estimated, and the owner and occupier compensated accordingly.

Removal.

This being in most cases a small matter, only a nominal compensation, if any, is allowed.

Trade Fixtures.

These are estimated according to the value of the machinery and other works, the horse-power (whether by steam, water, or horse-labour), the capability of the works for production or the ordinary work of the farm, and the state of repair.

Loss of Trade Profits.

These are estimated according to the extent and nature of the business, whether the loss will be partial or entail the closing of an established business, and as to whether the occupier is owner, lessee, or tenant.

The value varies from one to six years' purchase of the profits, according to the circumstances.

Loss from Forced Sale.

This is, in some cases, considerable, but 10 per cent. is generally added as compensation for this loss.

CHAPTER IV.

LAND VALUATION, RIPARIAN RIGHTS, EASEMENTS, AND COMPENSATION—*continued.*

Riparian Rights and Compensation.

The proprietor of any land adjoining or abutting on a stream has certain privileges or rights known as "riparian" (Lat. "ripa," a "river bank").

The law relating to these rights has been, from time to time, set forth in many well-known cases, to some of which further reference will be made.

In accordance with English law, the property in water flowing in a river or stream in its natural course belongs to no one, but the use of it to every one having a right of access to it.

In Miner *v.* Gilmour, Lord Kingsdown observed as follows: "By the general law applicable to running streams, every riparian proprietor has a right to what may be called the ordinary use of the water flowing past his land —for instance, the reasonable use of the water for his domestic purposes, and for his cattle, and this without regard to the effect which such use may have in case of deficiency upon proprietors lower down the stream. But, further, he has a right to the use of it for any purpose, or what may be termed the extraordinary use of it, provided that he does not thereby interfere with the rights of other proprietors, either above or below him. Subject to this condition, he may dam up for the purpose of a mill, or divert

the water for the purpose of irrigation; but he has no right to interrupt the regular flow of the stream, if he thereby interferes with the lawful use of the water by other proprietors, and inflicts upon them a sensible injury."

In the case of Chasemore *v.* Richards, it was held that "The right to the enjoyment of a natural stream of water on the surface belongs *naturali jure* to the proprietor of the adjoining land as a natural incidence to the right to the soil itself. He has the right to have it come to him in its natural state, in flow, quantity, and quality, and to go from him without obstruction, upon the same principle that he is entitled to the support of his neighbour's soil for his own in its natural state. And such a right depends in no way upon prescription, or the presumed grant of his neighbour, nor from the presumed acquiescence of the proprietors above and below."

Again, in Mason *v.* Hill, "A riparian proprietor can have no larger right than he has by nature against those above and below him. Hence the right to have a stream to flow in its natural state without diminution or alteration is an incident to the property in the land through which it passes; but flowing water is *publici juris*, not in the sense that it is a *bonum vacans*, to which the first occupant may acquire an exclusive right, but that it is public and common in this sense only, that all may reasonably use it who have a right of access to it; that none can have any property in the water itself, except in the particular portion which he may choose to abstract from the stream and take into his possession, and that during the time of his possession only."

If, then, a Local Sanitary Authority, or generally the promoters of a water-supply scheme, desire to utilize any spring or stream of water for that purpose, they must first come to terms with the owner of the land whereon the spring rises, or the riparian owner of that part of the stream from which they wish to take their supply. As such owner can only grant the limited powers which he himself possesses, terms must then be arranged with all the riparian owners lower down the stream who have

appropriated, or may appropriate, the water to a beneficial use. Such arrangements must be made in writing.

"If any works are proposed to be done affecting any water or water rights, the proper course to be observed by a Local Authority is to serve a notice under the 328th section of the Public Health Act, 1875, on all persons interested, specifying the particulars of the matters and things intended to be done. Then will follow, either the consent of the parties interested, or there will be a reference to arbitration, and then will follow, either compensation for injury, if the injury can be compensated in money, or an abandonment of the proposed works." There is recourse to the promotion of a private Bill in Parliament, but this is too expensive, except in the case of very large schemes.

Water rights require to be very carefully dealt with, and every detail should be settled before the works are commenced.

In the first instance, the quantity of water should be gauged, by methods to be described later, the fall of the stream ascertained, and a careful investigation made of the use to which the water is put below the point of the proposed intake. The quantity of water required by any mills or other machinery worked by the stream should be obtained, as well as the quantity used for domestic, dairy, and other purposes.

The head waters of a stream are usually required for the purposes of waterworks when storage is necessary. It therefore becomes a matter for serious consideration whether such abstraction, either wholly or partially, will deprive the riparian owners below the site of the proposed works of sufficient water for the purposes of fishing, irrigation, mills, factories, boundary fences, and other matters. The compensation in such cases is either given in kind or in money. The quantity in the former case varies from one-third to one-tenth of the available annual yield of the gathering ground, necessitating in numerous cases the construction of "compensation reservoirs." The object of these reservoirs is to store the flood water, so as to maintain a

continuous or intermittent flow, as may be arranged or settled by Provisional Order or Act of Parliament. When the proprietors are disposed to treat, and are not numerous, it is better in most cases to purchase their rights and be relieved of a large proportion of the compensation water.

There is no property in underground water, and any proprietor may sink or dig wells and obtain water, even if by doing so the water in a neighbouring proprietor's well is abstracted or diverted into another channel. In some cases wells are sunk to the spring supplying a stream, which by intercepting the spring at a higher point may considerably reduce the flow of water in the stream.

"But although a landowner will not in general be restrained from drawing off the subterranean waters in the adjoining land, yet he will be restrained, if, in so doing, he drains off the water flowing *in a defined surface* channel through the adjoining land."

As an instance of the application of this principle, the following case is given. A large provincial water company recently promoted a Bill to enable them to sink wells at various points along a stream, and pump the water which percolated into them to a storage reservoir. The riparian owners and residents in the valley opposed the Bill with such success that the quantity of water to be allowed to flow in the stream before pumping could proceed was so great as to render the Act when passed useless to the water company.

Much of the above information has been extracted from the valuable legal works of Messrs. Michael and Will, and Messrs. W. C. & A. Glen, to whom thanks are due.

Easements and Compensation.

In laying the various mains and branches in connection with a system of water supply, it frequently becomes necessary to lay pipes or tunnel through private property. In cases where the purchase of the freehold of the land is not made obligatory or desirable, an easement is obtained.

The term "easement" is defined in an ancient work called the "Terms de la Ley" as follows: "An easement is a privilege that one neighbour hath of another by writing or prescription, without profit, as a way or sink through his land or such like."

An easement giving the right to lay pipes, build culverts, drive tunnels, etc., for the purpose of conveying water, implies a right of entry at all times for repairs or other purposes rendered necessary for its proper enjoyment. And, further, the person to whom the easement is granted may prevent the owner of the land from doing anything to interfere with such a right—as, for instance, building houses or planting trees over the line of easement, or otherwise placing any obstruction to the full and proper enjoyment by the purchaser thereof.

In the case of Pomfret *v.* Ricroft, Twysden, J., observed as follows: "If a man gives me a licence to lay pipes of lead in his land to convey water to my cistern, I may afterwards enter and dig the land to mend the pipes, though the soil belongs to another and not to me. Whoever grants a thing is supposed also tacitly to grant that without which the grant itself would be of no effect."

In the case of Goodheart *v.* Hyett, the owner of the land commenced building over the line of easement, and the owner of the easement sought to restrain him from doing so, on the ground that if the house was built it would be impossible, or not reasonably practicable, for the owner of the easement to have access to the pipe for repairs. The Court restrained the owner of the land from building over the line of easement.

In taking into consideration the compensation due to the owner of the land, the elements of claim for damage may be classified as follows:—

1. The privilege of carrying a certain thing, either continuously or intermittently, over or under the land to the profit of the purchaser.
2. The right of entry to pipe or culvert at any time.
3. The right of preventing any buildings or other

obstructions from being erected or built on the line of easement.

4. The interference with the profitable laying out of the land for building sites or otherwise.

5. The driving of the tunnel or excavation of the trench may have the effect of withdrawing the moisture from the crops, and thus depreciate the value of the land for agricultural purposes. On the other hand, it may be of great benefit where the land is marshy or waterlogged.

6. The driving of the tunnel or excavation of the trench may intercept or divert underground water which previously had risen on other portions of the land.

The methods adopted by experts, and the results arrived at, differ so materially as to render it impossible to give any common data upon which the valuation is based. This is chiefly due to the variety of opinions held as to what constitute the elements of damage, even on adjoining land when precisely the same conditions prevail.

The following are, however, a few of the methods adopted by experienced valuers :—

1. The length of the easement in yards is multiplied successively by 33 feet, the value per acre, and thirty years' purchase.

2. The length of the easement in yards is multiplied successively by 4 yards, the value per acre, and from forty to fifty years' purchase, and the result divided equally between the two parties to the easement.

3. The length of the easement in yards is multiplied by 8 yards, and then by half the value of the fee simple.

To the results arrived at by any of the above methods a fixed price must be added for ventilating shafts, air-valve standards, or other surface arrangements, varying from 5*s.* to £6 each.

The widths taken for easement for the purposes of valuation are somewhat elastic, varying from 6 feet to 66 feet. For pipes or culverts up to 2 feet diameter, the width is frequently taken as 12 feet; for larger culverts the width taken generally varies from 12 feet to 33 feet.

The average price is taken by some valuers at £3 per chain lineal, irrespective of width. Other valuers take from 3*d*. to 2*s*. per lineal yard for agricultural land, and from 5*s*. to £6 per lineal yard for building land, as the average price throughout the length of the easement.

A Local Authority has full powers as to laying pipes, etc., along the highways under its control within its own district. With regard to highways outside its district, should any persons having the care of such highways object in writing, pipes must not be laid without the consent of the Local Government Board. The easement is usually granted conditionally upon the undertakers reinstating the road and keeping it in repair for one year after the completion of the work, to the satisfaction of the authority granting the easement. In some cases the authority agree to accept a fixed sum per mile, relieving the undertakers from any further liability.

CHAPTER V.

GRAVITATION.

It has already been stated that a gravitation supply should always be adopted where possible, especially for rural districts.

The principal requirements of a gravitation scheme are as follows :—

1. That the spring or source of supply is situated at a sufficient elevation with regard to the place to be supplied, so as to produce a velocity in the pipes sufficient to deliver the quantity of water required.

2. That the intervening ground along the proposed line of pipes, between the source of supply and the district to be supplied, does not rise appreciably above the hydraulic mean gradient of the system.

3. That the pipes are selected of such dimensions as will discharge the requisite quantity without necessitating a greater velocity than 3 feet per second.

4. That sufficient storage-room is afforded, so as to allow for exceptional demands upon the supply, as well as for diminution in the latter in very dry seasons.

The subject of the flow of water in pipes has been so elaborately dealt with in the various text-books, that only the leading principles affecting actual practice will be dealt with here.

In the annexed figure (Fig. 1) a pipe is shown connecting two reservoirs A and B, in each of which the water is always kept at the same level. Vertical pipes, C_1, C_2, C_3, C_4, open at the upper end, are attached at intervals to the pipe AB. If

the extreme end B of the pipe AB be closed, the water will stand in the pipes C_1, C_2, C_3, C_4, at the level of the horizontal line AD, through the surface of the water in the reservoir A.

As soon, however, as the end of the pipe at B is opened, and the water is allowed to flow uninterruptedly from the reservoir A to the reservoir B, the level of the water in the pipes C_1, C_2, C_3, C_4, will sink to E_1, E_2, E_3 E_4, respectively. The line connecting the points E_1, E_2, E_3, E_4 is called the hydraulic mean gradient, or virtual slope of the system, and if the pipe AB be of uniform section throughout its length, the hydraulic mean gradient will be a straight line joining the surface of the water in A and B.

This gradient is represented by the height of the reservoir A above the reservoir B, divided by the length of the pipe, which is the sine of the angle made by the line of the gradient with the horizontal. It has been found that the velocity acquired by water flowing through a pipe varies directly as the square root of the quantity representing the hydraulic mean gradient, and directly as the square root of the diameter of the pipe.

The section of the lines C_1, C_2, C_3, C_4, situated between the line of pipe AB, and the hydraulic mean gradient denotes the pressure (in addition to the atmospheric pressure) in the pipe at those points, and it is evident that when the line of pipe and the hydraulic mean gradient coincide, the pipe may be replaced by an open channel.

Suppose, however, that the line of pipe rises above the hydraulic mean gradient, it is clear that the pressure at that point is less than the atmospheric pressure by an amount indicated by the distance of the pipe above the hydraulic mean gradient. When this distance exceeds the height of a column of water which can be supported by the atmospheric pressure (34 feet), the pressure becomes nil, and flow ceases. Practically, the distance should never exceed 25 feet. When the pressure at any point F (Fig. 2) is less than the atmospheric pressure, the flow continues by syphonage until sufficient air is extracted from the water, which fills the summit of the pipe, and syphonage ceases. The pipe at

this point may then be replaced by an open channel. The pipe is practically divided into two sections, AF, FB, and

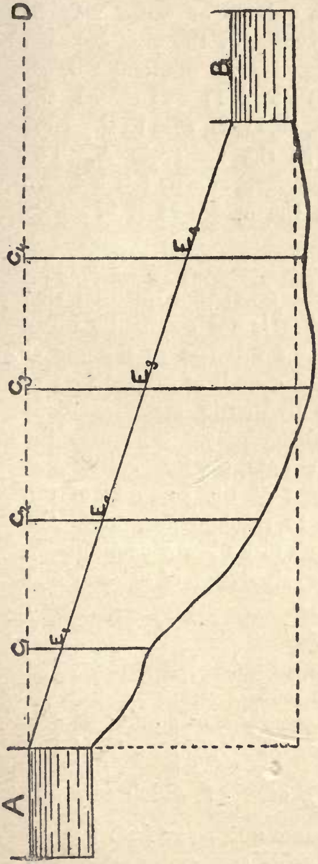


FIG. 1.

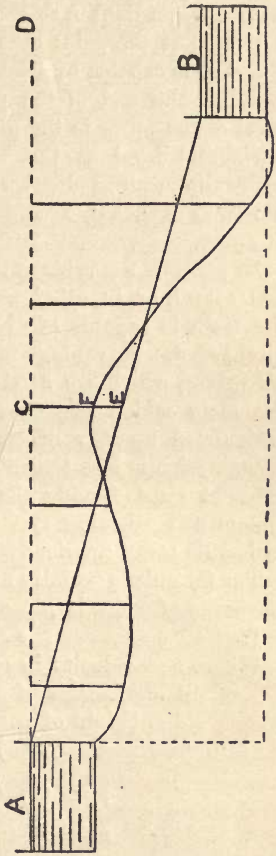


FIG. 2.

the discharge at B must depend upon the quantity which the first section AF is capable of delivering at the point F.

As the velocity, and, therefore, the discharge, depend upon the diameter of the pipe and upon the hydraulic mean

gradient, a deficiency in the latter may be made up by an increase in the former. In the case just cited, the diameter of the pipe between A and F should be increased, so that, with the gradient AF, the same volume of water may be delivered at the point F as the portion of the pipe between F and B is capable of discharging with the gradient FB.

When the end of the pipe B (Fig. 1) was closed, the level of the water in the pipes C_1, C_2, C_3, C_4 rose to the same horizontal level as the water in the reservoir A. The hydraulic mean gradient will, therefore, rise or fall between the lines AD, AB, according as the orifice at B is closed or open.

In practice the orifice at B is never constantly open to its full extent, or, in other words, the maximum quantity that the main is capable of discharging is not constantly being discharged. Advantage is taken of this fact in the use of air-valves, which are fixed at the summit of all sections of the main which rise above the hydraulic mean gradient (calculated upon a maximum discharge). Whenever the consumption is less than the maximum, the hydraulic mean gradient rises, forcing the air out of the summits of the system and allowing syphonage to recommence, when the hydraulic mean gradient falls back to its lower position.

The formulæ generally used for calculation of velocity and discharge of water in pipes are:—

1. $$v = 39\sqrt{di}$$

Where v = velocity in feet per second.

„ d = diameter of pipe in feet.

„ i = height of point of supply above point of discharge (h) divided by the length of the pipe (l) $\left(= \frac{h}{l}\right)$, each of which must be referred to the same unit—say feet.

2. $$g = \sqrt{\frac{(3d)^5 \times h}{l}}$$

Where g = discharge in gallons per minute.

„ d = diameter of pipe in inches.

„ h = head in feet.

„ l = length of pipe in yards.

These formulæ allow a sufficient margin for subsequent rusting in the pipes.

By substituting the value 3 for v in the first equation, the following result is obtained—

$$d = \cdot 006 \times \frac{l}{h}$$

which enables the diameter of a pipe to be calculated where the head and length are known, so that the velocity may be three feet per second.

A gravitation supply usually requires a larger storage capacity than a pumping supply, as the sources are generally small at such elevations as will allow of gravitation. The amount of storage is regulated by the volume and permanency of the source. This matter, together with the subject of collection, will be dealt with subsequently.

When the source of supply is situated below the level of the immediately surrounding ground, and considerable expense would be entailed by excavation to a sufficient depth to allow a fall in the direction of supply, recourse may be had to a syphon. The summit of the syphon must theoretically not exceed 34 feet above the level of the surface of the water from which the supply is to be drawn; practically about 25 feet is the limit. Such systems of supply have been adopted at Abingdon and Warwick.

The syphon may be charged by an air-pump attached to the longer leg, the communication with the main being cut off by means of a sluice-valve; or the extremities of both legs may be closed by means of sluice-valves and the apparatus filled with water through a cock at its summit; the cock is then closed and the sluice-valves opened, when flow immediately commences.

When the water is highly aërated the syphon has to be frequently recharged. In calculating discharge, the head must be measured to the surface of the water in the reservoir, and not to the summit of the syphon.

CHAPTER VI.

PUMPING BY STEAM, GAS, PETROLEUM, WATER, AND WIND POWER.

THE various systems of motive power for pumping are determined by the work to be performed, the accessibility of the pumping station, and by local and other conditions depending upon the particular circumstances of each case.

The unit of power in common use is the mechanical force necessary to perform a certain amount of work known as a horse power, and is equal to 33,000 lbs. raised one foot high per minute. The terms used to express horse-power being somewhat indefinite, a brief reference may not be out of place.

Nominal horse-power is a commercial term for stating the size of an engine without regard to the actual power it will develop.

Actual or indicated horse-power is the power calculated from a diagram of the work performed by the steam in the cylinder, one horse-power being equal to 33,000 lbs. lifted one foot high in one minute, or—

$$\text{I. h.p.} = \frac{\text{Units of work done per minute}}{33{,}000}$$

Effective or brake horse-power is measured by a friction brake or dynamometer, and represents the actual horse-power less the power absorbed by the working parts of the engine or motor.

It is only proposed to refer to the indicated horse-power except where otherwise stated.

Steam power as applied to pumping for waterworks, is of general application, and the results are more economical for heavy pumping than any other system. The engine for applying the power takes several well-known forms, among which may be mentioned the vertical, horizontal, beam, and Cornish engines, each of which has several types. Steam-engines are divided into two main systems—non-condensing and condensing. The former exhaust their steam direct into the atmosphere, and the steam is used at full pressure, either partially or throughout the stroke, sufficient allowance being made to cut off and avoid back pressure. Condensing engines exhaust their steam into a chamber termed a condenser, which is in a state of partial vacuum owing to the steam coming in contact with a number of tubes through or around which cold water is circulating, or, in some cases, a jet of cold water. The air and condensed water are removed by an air-pump, which is worked from the engine. The water from the condensers having an average temperature of 100 degrees Fahrenheit, is frequently used for feeding the boilers, but care must be taken to prevent grease getting into it and injuring the boilers. Condensing engines are divided into systems according to the number of expansions employed —viz. simple or single cylinder, compound or two cylinders, triple or three cylinders, and so on as the range of expansion increases. The simple engine consists of a single cylinder in which the steam is exhausted by the condenser after having done its work. The compound engine consists of two cylinders; the steam after being partially expanded in the small or high pressure cylinder is exhausted into the large, or low pressure cylinder, and there undergoes further expansion before being exhausted by the condenser. The chief difference between the simple and compound systems is that in the former case the whole range of the temperature occurs in one cylinder, whereas in the latter it is divided between the two cylinders, and the loss due to the extreme variation of temperature in one cylinder is thereby prevented. Theoretically the low-pressure cylinder with steam pressure and expansion the same as the high-

pressure cylinder worked on the simple or single system would develop more power than the two combined; but practically, owing to the various losses that occur, the theoretical results cannot be attained.

The advantages of the non-condensing engine are—

1. The simplicity of the mechanism and construction.
2. The easy accessibility to its working parts, and
3. Inexpensive foundations.

In fuel economy, however, it does not compare favourably with the condensing engine for permanent work. It is chiefly used in waterworks for temporary purposes, or where only a small engine is required.

The advantage of the condensing engine is its economy of fuel. The first cost is high, and the foundations are expensive, but for heavy pumping the satisfactory working of these engines, together with a fuel economy of about 25 per cent. over the non-condensing engines, outweigh any other considerations.

The Consumption of Coal per I.H.P. per Hour.

Non-condensing engines from 4 to 7 lbs.

Condensing engines (simple) from 3 to 5 lbs.

Condensing engines (compound) from $1\frac{1}{2}$ to 3 lbs.

Gas power is utilized by the explosion of a mixture of coal gas and air in the cylinder, which, acting on the piston, gives the requisite motion. The charge consists of air next the piston combining gradually with a mixture of gas and air, which becomes stronger until the firing point is reached.

This gradual increase of explosive strength has the effect of doing the work gradually and preventing shocks, as well as sustaining the pressure at the end of the stroke.

Pumping by gas has many advantages over the use of small steam engines—

1. There is no loss when the engine is not working.
2. It can be started by merely turning the gas on and lighting the jet, at the same time giving the fly-wheel a start.
3. It can be fixed in almost any position, and requires no

attention, as must be the case when a boiler and steam engine are used.

There are many forms of these engines, each claiming special advantages, and all giving satisfactory results.

The consumption of gas per indicated horse-power varies from $17\frac{1}{2}$ cubic feet per hour in the larger engines to 25 cubic feet per hour in the smaller sizes.

Where the ordinary illuminating gas is either too costly or not available, the Dowson Gas Producers are frequently adopted, giving a non-illuminating gas which costs from $2\frac{1}{2}d.$ to $4d.$ per 1,000 cubic feet.

Petroleum-power engines differ from the gas engines chiefly in the method of delivering the oil in measured quantities with the requisite quantity of air. The oil is stored in a tank of sufficient capacity to serve for 12 or 24 hours as required. The firing light is obtained from the flame of a lamp kept continually burning. The advantages of this engine for pumping are—

1. The cheapness of the oil.
2. The slight amount of attention required.
3. The small capital cost.
4. The facility of fixing in any position.

The cost for oil varies from $\frac{3}{4}d.$ to $1\frac{1}{2}d.$ per indicated horse-power per hour.

Water-power may be utilized for pumping in several different ways, among which are hydraulic rams, water-wheels, and turbines.

The hydraulic ram is frequently applied when the water is abundant and the fall moderate. The action is as follows: The momentum of the inflowing water when arrested is expended in forcing a portion of itself through the delivering-pipe into a tank or reservoir.

If H = Height of source of supply above the ram.
,, h = Height to which the water is to be forced.
,, Q = Volume of supply.
,, D = Volume delivered.

$$D = \frac{4Q}{7} \cdot \frac{H}{h}$$

The advantages of the ram are—

1. The simplicity of its parts.
2. The facility with which it can be fixed.
3. The little or no attention required.
4. Its moderate cost.

Water-wheels for driving pumps and other purposes are named according to the way in which they are acted on by the water.

1. *Overshot* when the water is delivered on the top of the wheel.

2. *Breast* when delivered about the centre, and—

3. *Undershot* when driven from the bottom, where there is a considerable velocity in the water.

The overshot wheel gives the greatest power, with the least expenditure of water, and is therefore applicable where the supply of water is scanty.

The horse-power (effective) is calculated as follows:—

$$\text{E.H.P.} = \frac{Q \times H \text{ in feet}}{C}$$

Q = Quantity of water in cubic feet per second.
H = Effective height of the fall in feet.
C = 13 for overshot wheels;
15 for breast wheels;
11·7 for high-breast wheels;
22 for undershot wheels.

Turbines, when carefully designed with regard to the conditions of working, are the best and most efficient motors. They are divided into two classes, pressure and impulse turbines, the former acting partly by impulse and partly by pressure, and the latter entirely by impulse. The turbine consist of a cylinder revolving horizontally, to which are attached spiral discs. The water is introduced at the top, and by its pressure on the sides and bottoms of the spiral chambers, causes the cylinder to rotate. The power is applied to the pumps by means of suitable gearing. In some cases an efficiency of 78 per cent. of the total power expended has been attained.

$$\text{Actual horse-power} = \cdot079\ Qh$$

Q = quantity of water passing through in cubic feet per second.

h = height of the fall in feet.

The theoretical horse-power contained in the water is calculated as follows:—

$$\text{T.H.P.} = \cdot001892\ Qh$$

$$Q = \frac{528\cdot5\ \text{T.H.P.}}{h}$$

Q = quantity of water in cubic feet per minute.

h = head of water in feet.

Effective Horse-power for Different Motors.

Theoretical power being	...	= 1·00
Turbine ...	... ...	= ·70
Overshot wheel	... ...	= ·68
High breast wheel ...	...	= ·60
Hydraulic ram	... ...	= ·60
Breast wheel	... ...	= ·55
Undershot wheel ...	...	= ·35

Wind-power is only economical for intermittent work, or where sufficient storage is provided for two or three days' supply. The wind pressure may generally be depended upon for seven or eight hours per day. The modern windmills for pumping are self-adjusting, and give exceedingly good results. They are being largely adopted for private supplies, or where their economical use permits.

$$\text{H.P.} = \frac{A\ \ V^3}{1{,}100{,}000}$$

A = Total area of sails in square feet.

V = Velocity of the wind in feet per second.

Table of the efficiency of windmills working eight hours per day, with a wind velocity of fifteen miles per hour during pumping.

Diam. of mill.	Revolutions per minute.	A.H.P. developed.	Quantity raised to a height of 100 feet.
Feet.			Galls.
12	55	$\frac{1}{4}$	3,375
15	50	$\frac{1}{3}$	5,000
18	45	$\frac{1}{2}$	10,000
20	40	$\frac{3}{4}$	12,500

TABLE OF WIND VELOCITY.

Velocity in feet per second	12·13	17·15	21·	24·25
Velocity in miles per hour	8·27	11·69	14·31	16·53
Description of Wind ...	Gentle	Slight breeze	Fresh breeze	Strong breeze

CHAPTER VII.

VARIOUS FORMS OF PUMPS.

The force acquired by steam or other motive power may be applied through the medium of a pump, in three ways: firstly, by suction or lifting; secondly, by forcing; thirdly, by a combination of the two systems, lifting and forcing.

The suction or lift pump (Fig. 3) is of common application for domestic supplies from wells or boreholes. It consists essentially of a cylinder or working barrel, with a suction pipe at the lower end, at the top of which is a valve, technically called a "clack." The delivery-pipe, or rising main, is attached to the upper end of the barrel, and through it a pump-rod, with a valve or bucket attached to its lower end, is worked up and down in the working-barrel. The upward movement of the bucket withdraws the pressure of the atmosphere from the surface of the water inside the suction pipe, and the pressure of the atmosphere on the surface of the water in the well forces the water up above the clack, or to such a height that the pressures on either side of the pipe are in equilibrium.

The water retained by the clack passed through the valve at the lower end of the pump-rod as the latter moves downwards, and is raised at each successive stroke until it reaches the top of the rising main or delivery-pipe, which in open-topped pumps is the top pump-tree or pipe. In small pumps, where the pump-rod works through a stuffing-box or gland (Fig. 4), the water can be raised to any required height, but for economical purposes it is not advantageous to lift it higher than 30 feet above the top

of the pump. The height of the clack in the upper end of the suction-pipe should not exceed 25 feet above the lowest level of the water in the well, the best results being obtained from 10 feet to 15 feet, and in high speeds the shorter the suction the greater the efficiency. Although theoretically, when the barometer is standing at 30 inches, the water should rise in the suction-pipe to a height of 33·99 feet from the surface of the water (the specific gravity of mercury being $13{\cdot}596 \times 30 \div 12 = 33{\cdot}99$), it is impossible in

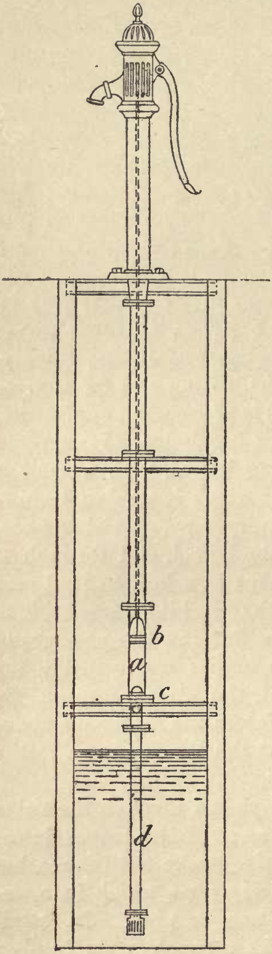


FIG. 3.
a, Working barrel; *b*, bucket; *c*, clack; *d*, suction.

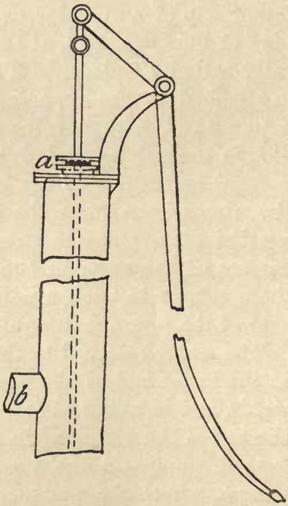


FIG. 4.
a, Stuffing-box; *b*, delivery-main.

practice to obtain so perfect a vacuum as to allow the water to rise this height, owing to the variations of atmospheric pressure, imperfect joints, and the friction of the pump. The power to work the lift-pump is transmitted by rods working from a beam, or by bell-cranks, or, in a few cases, by direct action, as in the Bull engine. When worked by manual labour, either a lever or wheel and handle are used. In deep wells the lift-pump is generally used to lift the water to a tank at the surface, from which it is taken by force, or bucket and plunger pumps, and delivered at the height required. The price of the ordinary lift-pump, with a working barrel, 3 inches in diameter, complete, for a depth of 30 feet, is £5, and from 2*s.* 6*d.* to 2*s.* 9*d.* per foot beyond that depth. The capacity of this pump when worked by hand is equal to 400 gallons per hour, lifted from a depth of 30 feet. A double or "two-throw" pump (Fig. 5), the diameter of the barrels being 3 inches and the stroke 10 inches, worked from the surface by rods, and driven by a horse and gearing, will cost about £35, including 20 feet of suction pipe and 50 feet of rising main (or delivery-pipe), and air-vessel complete.

Approximate quantities in gallons raised per hour by single, double, and treble-barrel pumps working at a uniform speed of 20 strokes per minute—

Dim. of pumps.	Length of stroke.	Single barrel.	Double barrel.	Treble barrel.
Inches.	Inches.			
2½	9	165	330	495
3	9	240	480	720
3½	9	310	620	930
4	10	480	960	1440
4	12	575	1150	1725
5	12	900	1800	2700
5	15	1125	2250	3375
6	12	1280	2560	3840
6	15	1600	3200	4800
6	18	1920	3840	5760

These quantities raised assume the horse to travel at

an average rate of three miles per hour, the pumps thus making twenty strokes per minute with the single speed gear. Pumps up to 4 inch barrel may be worked at 30 strokes per minute; unless the height the water has to be

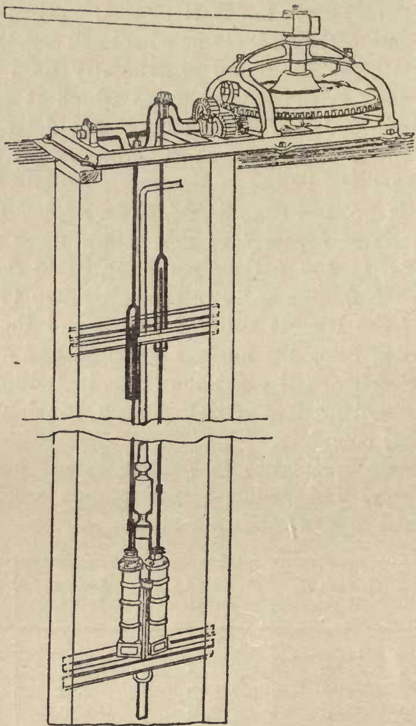


FIG. 5.

raised is great, the speed of the larger sizes should vary from 20 to 25 strokes per minute according to the lift.

The plunger or force-pump (Fig. 6) consists of a cylinder or working barrel, in which the piston or plunger works up and down through a stuffing-box or gland. The plunger is

either hollow or of solid metal, according to the conditions required, and may consist of one or more plungers, each working in its own barrel. The working barrel is of cast iron (or preferably of brass or bronze), and connected at one end with the delivery pipe, with valve-box and air-vessel beyond. The suction-pipe and valve-box are at the other end. This pump works either horizontally or vertically, and its action is as follows: in the upstroke of the plunger a vacuum is created which allows the water to enter through the suction-pipe into the working barrel and body of the pump, filling the space left by the plunger. The water is retained by a clack or valve at the top of the suction-pipe, and is again forced by the downstroke of the plunger through the delivery-pipe, being retained by the delivery-valve, and rises at each successive stroke until it reaches the point of discharge. During the up-stroke of the plunger the forward motion of the water through the delivery-pipe would cease, and the discharge would therefore become intermittent instead of continuous. This is avoided by the

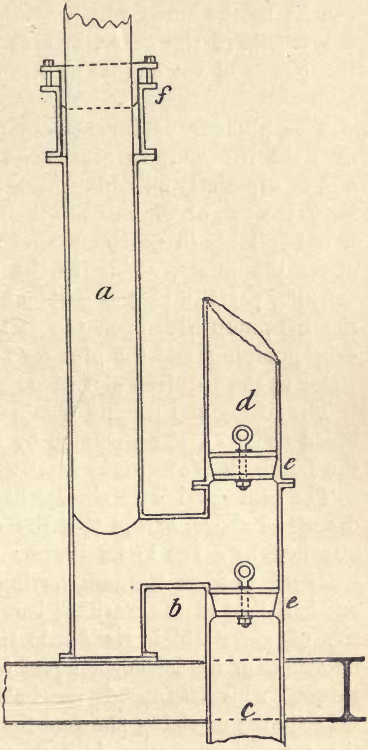


FIG. 6.

a, Plunger; *b*, H-piece with doors; *c*, suction; *d*, rising main; *e*, valves; *f*, stuffing-box.

use of an air-vessel, the air of which being compressed during the descent of the piston or plunger re-acts and forces the water through the delivery main during the up-stroke. This prevents the shock to the working parts caused by the force which would be required to overcome the inertia of the water, and at the same time economizes the power of the engine by keeping the water in constant motion.

The plunger or force-pump possesses great advantages over the lift-pump in most cases where it can be employed, and is especially suitable where considerable height has to be overcome, or where continuous working is required. It is not suitable in positions where the water is likely to rise above the pump, owing to the difficulty of access to the working parts in case of accident. In deep wells, therefore, the lift-pump with open top is to be recommended for the deep-pumping, and the plunger for subsequently raising the water to the required elevation.

The lifting and forcing pump, or bucket and plunger combined (Fig. 7), was invented by Perkins, and introduced at the Lambeth Waterworks in 1848.

The construction is similar to that of the forcing-pump described above, except that the ram or piston has a bucket attached by a rod to its lower end. The upper portion is enlarged to form the ram, having a sectional area equal to one-half that of the working barrel. The theoretical quantity of water which rises into the working barrel at each up-stroke of the bucket is equal to the capacity of the barrel through which it ascends, one-half of which quantity rises in the delivery or rising main on the descent of the bucket, and the remaining portion is discharged during the following up-stroke. The delivery from the pump is therefore continuous. This is one of the best forms of double-acting pump, as it possesses nearly all the simplicity of the single-acting pump, and is free from the defects of the four-valve pumps. The quantity of water delivered at the up and down stroke is no more than with a pump with single action, the difference being that the double-action gives a

continuous, and the single-action an intermittent delivery. This form of pump is used in nearly all the large waterworks.

Horizontal engines and pumps, mainly direct acting, are frequently used for small supplies, and improvements during the last few years have justified their use in many of the largest waterworks. The Worthington, Deane, Davidson, and other well-known types give good results; they are principally used for forcing to service reservoirs.

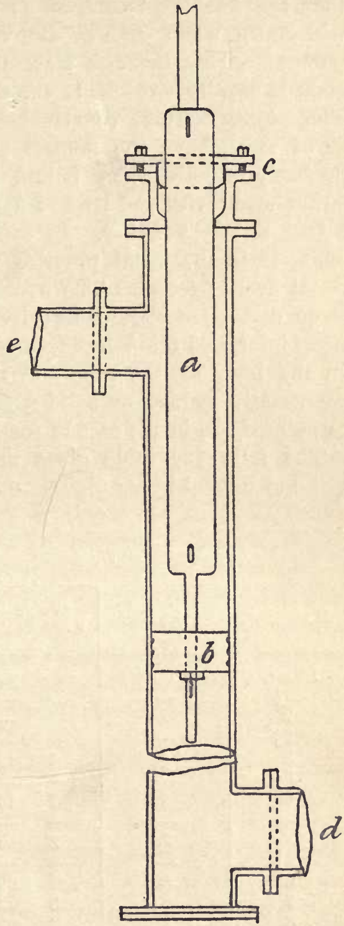


FIG. 7.

a, Plunger; *b*, bucket; *c*, stuffing-box; *d*, connection to valve chamber; *e*, rising main with stop back valve and air vessel.

The pump-trees or pipes which constitute the suction-pipe and rising main, form so important and costly a portion of the pumping apparatus as to require careful design. They are usually 9 feet long, and consist of cast-iron pipes with flanges, or of wrought-iron or steel tubes, riveted or welded with flange-joints. The cast-iron pipes should be made of hard mottled-grey iron, re-melted in the cupola, and cast vertically in loam, care being taken to keep the metal of uniform thickness and truly cylindrical. In open-topped

pumps the diameter is made from ½ inch to 1½ inch greater than the working barrel, so as to enable the valves to be withdrawn when repairs are necessary. In close-topped pumps working through a stuffing-box or gland the rising main is usually two-thirds the area of the working barrel. The pipes, whether constructed of cast or wrought iron, or of steel, have the flanges machine-faced so as to be perfectly plumb when bolted together. The joints are either made with red lead or flannel steeped in tallow, and bolted tightly together. In considerable heights of rising main, it is the usual practice to reduce the thickness of metal every 54 feet. The wrought-iron or steel tubes for large diameters should be riveted together with a butt-strap joint, and the flange formed with an angle-iron shrunk on the body of the pipe and riveted. The smaller sizes are usually welded or solid-drawn. The pipes should all be painted, or, in the case of small tubes, galvanized.

The following table gives the weight and thickness of cast and wrought-iron pipes:—

Cast-iron flanged Pipes.				Wrought-iron Tubes.	
Diameter.	Thickness.	Weight of 9 feet lengths.		Thickness.	Weight per foot.
Inches.	Inches.	cwts.	lbs.	B. W. G.	lbs.
1½	—	—	—	14	1·37
2	—	—	—	14	1·81
2½	—	—	—	12	2·24
3	⅜	1	12	11	2·68
3½	—	—	—	10	3·11
4	⅜	1	49	10	3·55
4½	—	—	—	10	3·98
5	$\frac{7}{16}$	2	10	9	4·42
5½	—	—	—	9	4·85
6	$\frac{7}{16}$	2	65	9	5·29
7	½	3	32	—	—
8	½	3	81	—	—
9	$\frac{9}{16}$	4	80	—	—
10	$\frac{9}{16}$	5	23	—	—
11	$\frac{9}{16}$	5	79	—	—
12	⅝	6	103	—	—

CHAPTER VIII.

VARIOUS FORMS OF PUMPS—*continued*.

The working-barrel is formed of hard grey metal, bored out truly cylindrical in the larger pumps, and with a gun-metal or copper liner inserted in the smaller ones. The ends are slightly bell-mouthed, and are made sufficiently long to allow from 3 inches to 12 inches clearance beyond the actual stroke of the pump. The thickness of the metal is greater than that of the rising main, owing to the wear and tear, and to allow for reboring when necessary. In forcing-pumps the top of the barrel is made tight, with a stuffing-box or gland packed with metallic material, which can be renewed without stopping the working of the pump.

The clack or waist-piece contains a turned conical seating for the valve. In some cases, in open-topped pumps, a second seating of larger diameter is provided above the one generally in use. The advantage of this arrangement is that it enables a temporary valve to be lowered, in the event of an accident, to act until access can be had to the defective valve. Door-pieces are fixed so as to enable the bucket or clack to be examined or changed. These, of course, are only available when the water is below the level at which they are situated. The diameter of the suction-pipe may be reduced below the level of the clack or valve to from one-half to two-thirds of the area of the working-barrel, except in the case of quick-running pumps, when the diameter should not be less than that of the working-barrel.

The rose, windbore, or strainer, at the bottom of the suction-pipes takes various shapes; but care must be taken to make the aggregate area of the apertures not less than from two to two and a half times the area of the suction-pipe.

The pump-rods are either made of wrought-iron with flanged joints bolted together, or of pitch-pine connected by means of iron side-plates and bolts running through the rods. Hard-wood guides are affixed to the rods when working in the rising main, and metal rollers guide the rods when working a plunger.

The valves, of which there are at least two in every pump, either fixed or movable, require the most careful attention, as they frequently cause a large portion of the power of the pumping apparatus to be lost. It is essential that they should offer little resistance to the passage of the water in one direction, and close the passage quickly and entirely in the contrary direction, so as to prevent slip. The weight of the valve should be sufficient to close without knocking, and be light enough to be lifted without offering undue resistance to the water. In high lifts the valve is usually calculated at 1 lb. in weight per square inch of area, equal to 2·3 feet of water; and for low lifts it varies from $\frac{1}{4}$ lb. to $\frac{1}{2}$ lb. per square inch of area. The velocity of the water through the valves should not exceed 5 feet per second. The valves used in pumps belong to one of two classes, the hinged or door, and the spindle valve.

The flap or hinged valve (Fig. 8) consists of a flap or

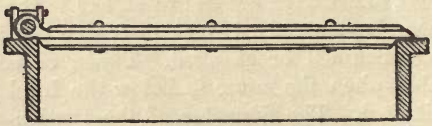


FIG. 8.

sheet of leather, stiffened and weighted with metal plates, working on a hinge, the shell being of wood or metal.

The butterfly valve (Fig. 9) is of frequent application,

and derives its name from the wings or flaps, consisting of semi-circular discs hinged to the centre of the shell. The

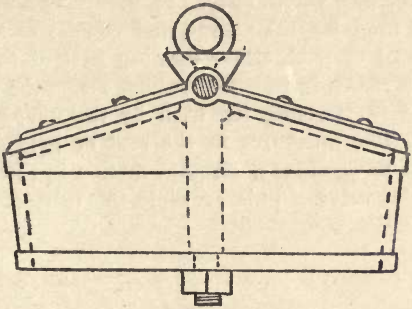


FIG. 9.

wings, or flaps, are stiffened and weighted with metal plates, similar to the flap, or hinged valve, and the shell is formed of wood or metal.

The mitre valve (Fig. 10), used mainly in horizontal

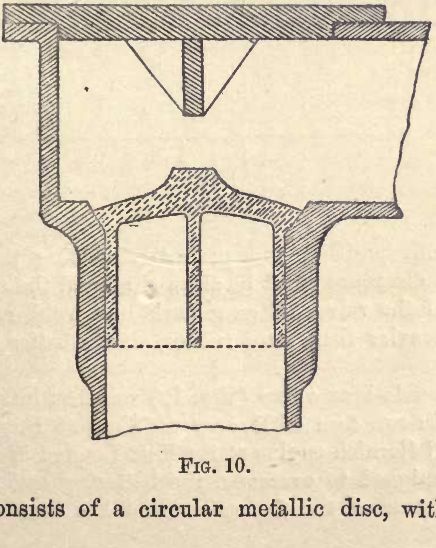


FIG. 10.

pumps, consists of a circular metallic disc, with conical

face, the upper portion having a short spindle to limit its lift, and feathers below to guide the valve on to its seat.

The rubber disc valves (Fig. 11), both single and double, are largely used for lift-pumps, and consist of an iron or gun-metal seat or grid, either forming part of the shell or fitting into a recess in it. The rubber forms the valve, and is prevented from rising too high by the guard shown in the figure. The apertures in the seat or grid are placed at an angle to produce a circular motion in the water and thence in the valve. This prevents the valve from falling

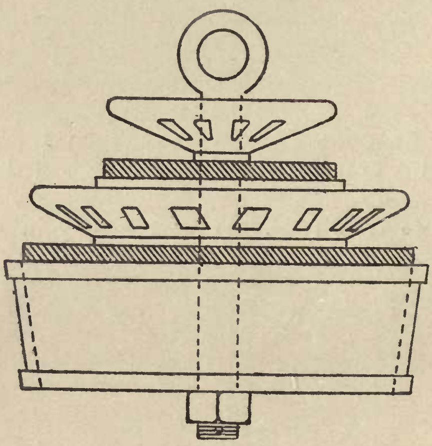


FIG. 11.

in the same position and gradually cutting the rubber. Sufficient clearance must be allowed around the spindle for the lift of the valve. Strong dark blue rubber, which is a little heavier than pure rubber, stands better for heavy work.

The double-beat valve (Fig. 12) was first introduced by the well-known firm of Harvey & West, of Hayle, for the Wicksteed Cornish engine at the East London Waterworks. It was designed to overcome the battering and the great wear and tear of the flap-valves, and has been used with

little modification up to the present time. It consists of a circular ring, on which the lower part of the valve beats, and a similar ring of less diameter on the plate of which the upper part beats, forming "the double beat." The

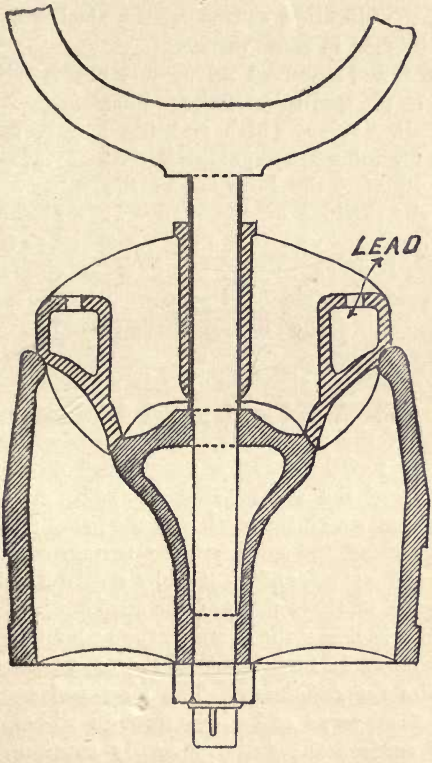


FIG. 12.

beats are formed of lignum-vitæ, white metal, or leather. They are fixed to the valve and beat on a gun-metal seat. The valve consists of a double cylinder, one within the other, forming one piece, open top and bottom, and working on a spindle.

The webs connecting the parts together are placed at a slight angle, to cause the valve to rotate during the influx of water every time it rises and falls, which keeps the beats perfect and tends to prevent grooving. The great advantage of this valve is its small lift, owing to the two openings for discharge, the vibration caused by the closing of the valve being diminished in consequence.

The three- and four-beat valves only present slight variations, due to the multiple number of beats.

The Riedler valve, which is being largely used on the Continent for quick-speed pumps, is giving great satisfaction. Professor Riedler, the inventor of the valve, has made a series of observations on the action of valves (Indicator-Versuche au Pumpen), and the valve referred to is the result of his investigations, with a view to remedying the defects of valves used in quick-speed pumps. The lift is performed automatically, and the closing of the valve is accomplished by a spring and lever.

The air-vessel is simply a cylindrical vessel of cast- or wrought-iron, with a dome-top and inlet and outlet connections from the pump at or near the base. The air in the upper part of the vessel is compressed until it balances the pressure of the water being pumped. At those parts of the stroke at which the motion of the pump piston exceeds the average speed, the surplus water further compresses the air to a small extent, and is thereby received into the air-vessel; again, at those parts of the stroke where the speed of the piston is below the average, the water thus stored up in the air-vessel is forced out by the expansion of the air, and supplies the deficiency. The air-vessel equalizes the strain on the pumps and pipes through which the water flows, and renders the delivery nearly constant, and is to the flow of water what the fly-wheel is to an engine. The only trouble in practice is that of keeping the air-vessel charged with air, as compressed air in contact with water is more or less rapidly absorbed. Provision should be made either by having a small pump for the purpose of pumping air into the air-vessel, or a small cock should be fixed on

the suction pipe to allow air to be pumped with the water.

The quantity of water contained in a pipe is determined by the formula $x = \cdot 00283 d^2 l$, in which x = quantity in gallons, d = diameter of pipe in inches, and l = length of pipe in inches; being based on the fact that the area of a circle in square inches is $\cdot 7854 d^2$, and a gallon contains 277 cubic inches, therefore $\frac{\cdot 7854 d^2 l}{277} = \cdot 00283 d^2 l$; and $x \times 10$ = weight in lbs., the weight of a gallon of water being 10 lbs.

To find the pressure of water in a pipe.—The pressure in lbs. per square inch is determined by the formula, $x = \cdot 433 h$, in which x = the pressure in lbs. per square inch, h = the head or height of water in feet; being based on the fact that a cubic foot of water weighs 62·4 lbs., and a square foot contains 144 square inches, therefore $\frac{62 \cdot 4}{144} = \cdot 433$ lbs.

The quantity of water delivered at each stroke of a pump is obtained by means of the formula given for the contents of a pipe. If d = the diameter of the working barrel or plunger in inches, l = the length of stroke in inches.

The quantity delivered per minute is determined by the number of strokes per minute multiplied by $\cdot 00283 d^2 l$.

These calculations make no allowance for slip, which varies from 5 to 15 per cent. or more, according to the condition of the pumps. The amount of slip is determined by accurately measuring the quantity of water delivered by the pumps into a cistern or tank of known capacity, or over a weir, and comparing the quantity with the calculated delivery, according to the dimensions of the pump. The method of gauging over weirs will be described in a future chapter.

CHAPTER IX.

RAINFALL, SPRINGS, STREAMS, AND THEIR MODE OF MEASUREMENT.

The moisture which is constantly being evaporated from the sea and other water surfaces is carried by the air, and is returned as rain and snow to feed the springs and streams, and is again, in turn, evaporated to supply the sources of rainfall. There is always moisture present in the air, varying according to the season and situation. In this country the average proportion is stated by eminent authorities to be about 1½ per cent. When there is a considerable amount of moisture in the air, approaching saturation, a slight reduction of temperature causes the moisture to become visible in the form of mist, rain, hail, or snow.

The rainfall of a district depends largely upon the position of its mountain ranges and forests, together with the direction of the prevalent winds. It is a matter of common observation in this country that the western and southern shores have an annual rainfall considerably in excess of the eastern shore. The rainfall on the western coast varies from 40 to 70 inches per annum, and in an exceptional case, in 1883, the great depth of 190·28 inches was recorded at the Stye, in Cumberland. The rainfall on the southern coast varies from 30 to 40 inches, and on the eastern coast from 20 to 30 inches, with an extremely low rainfall in 1883 of 18·71 inches at Clacton, in Essex.

The distribution of rainfall is very variable over the surface of the globe, due to the peculiar conditions

prevailing in each district. In Great Britain, the average fall is about 33 inches, with considerable variation. Spain has about 100 inches on the Atlantic Coast, and from 8 to 10 inches at Madrid; India from 10 to 600 inches; in Australia the average fall is about 25 inches; North America, 40 to 90 inches; South America, from *nil* up to 270 inches; and in Africa, from *nil* up to 40 inches. The areas over which an occasional shower falls at long intervals, exceeding a year in many cases, and termed rainless districts, are the deserts of North Africa, Arabia, Persia, Beloochistan, Thibet, Mexico, Guatemala, California, Peru, and Chili.

There are many cases recorded of excessive rainfall occurring within short periods in this country, causing the bursting of embankments, and floods of great magnitude, where sufficient means of discharging the flood-waters, at such times, is absent. Buchan states that 3 inches is not infrequently recorded in 24 hours in the Highlands of Scotland. At Seathwaite, in Cumberland, 6·62 inches fell on November 27, 1848. A remarkable fall was recorded at the Newport Waterworks reservoir during the 24 hours ending 9 a.m. on July 15, 1875, of 5·33 inches; the same storm was the cause of two small reservoir disasters, viz. at the Rogers Pond reservoir, at Cwm Carn, Monmouthshire, and at the Blakeney Brook reservoir at Cinderford, in Gloucestershire.

In estimating the available rainfall for water supply, it is the minimum rainfall on which all the calculations must be based. Mr. G. J. Symonds, F.R.S., who has done such valuable service to the country in organizing the complete system of record of rainfall observations, gives the following proportions as the limits of fluctuation in the rainfall. These are the result of a large number of observations extending over many years, and which, he states, will be within 7 per cent. of the actual fall:—

Wettest year, 45 per cent. more than the average.

Driest year, 33 per cent. less than the average.

Driest two consecutive years, 26 per cent. less than the average.

Driest three consecutive years, 21 per cent. less than the average.

The rainfall of a district is estimated from actual measurement by means of rain-gauges. These observations should be taken daily at or about the same time—usually 9 a.m. The number of guages for any district depends upon the extent of the catchment area or water-shed, and upon its altitude. The "Snowdon" pattern of rain-gauge (Fig. 13) is frequently adopted for waterworks purposes. It has a

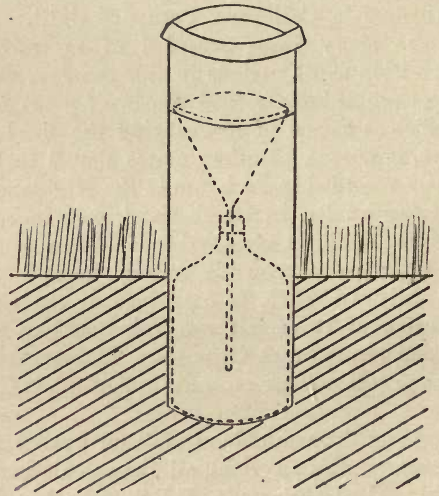


Fig. 13

diameter of 5 or 8 inches. It should be placed on a level base of stone or similar material, and either a recess cut in the stone to admit the gauge, or pegs driven around the cylinder to prevent lateral movement. The site should be on even ground, with plenty of open space, and at a distance of not less than one and a half times the height measured horizontally from plantations or buildings. The top of the gauge should stand 12 inches clear of the ground. The gauge consists of a copper cylinder, provided with a funnel

of the same metal to receive the rain and prevent evaporation. The tube of the funnel terminates in a glass cylinder, which retains the rain-water until the observer has measured the depth of water in a graduated glass measure for the purpose. The altitude of the rain-gauge should be carefully taken by connecting its height with the nearest ordnance bench-mark.

The rain and snow which fall on the surface of the earth are disposed of in the following ways:—

1. Evaporation.
2. Percolation.
3. The remainder flows off as storm or flood-water.

1. *Evaporation*, or the property of the water to rise in vapour, has received the attention of many eminent observers, among whom may be mentioned the names of Evans, at Nash Mills; Gilbert and Lawes, at Rothampstead; and Greaves, at Lea Bridge, near London. The latter found the annual evaporation from large water surfaces was about 21 inches, and was distributed in the following proportion during the year:—

January to March	4 inches.
April to May	8 "
June to September	7 "
October to December	2 "

The amount of evaporation from large water areas is in most cases equal to the rainfall, therefore in estimating the yield of a water-shed or catchment, the area of the lake or reservoir should be excluded. The evaporation from land surfaces varies according to the geological and physical conditions prevailing in the district, and any fixed rule is impossible. Steep slopes in the lower series of rocks afford the greatest flow over the surface, and little evaporation and percolation. Plantations lessen the loss by evaporation. The amount of evaporation on land surfaces in this country varies from 8 to 20 inches, and in hotter climates is much greater; in parts of India it varies from 55 to 90 inches, and on water surfaces the average is usually taken at 72 inches.

The Dead Sea and the Mediterranean afford examples of great evaporation.

2. *Percolation*, or the passage of rainfall through the surface of the ground, varies also according to the geological and physical conditions. The first recorded experiments in this country were made towards the end of the last century by Dr. Dalton, of Manchester, and have been continued by Dickenson and Evans, Gilbert and Lawes, Greaves, Latham, and others. In the evidence before the Royal Commission on Metropolitan Water Supply, 1893, the following particulars were given as to the percolation through 3 feet of soil, with grass growing on the surface, and 3 feet of chalk, also with grass growing on the surface, at Nash Mills, Hemel-Hempstead, and to these are appended the results obtained from Lea Bridge and Rothampstead:—

District.	Period.	Medium.	Rainfall.	Percolation.
		Feet.	Inches.	Inches.
Nash Mills	1842 to 1884	Soil 3	27·40	6·77
" "	1854 to 1884	Chalk 3	27·84	10·55
Lea Bridge	1852 to 1873	Soil 3	25·94	7·02
Rothampstead ...	1871 to 1892	Soil 5	30·11	13·90

In the Rothampstead experiments a solid block of earth was enclosed in a water-tight tank, and in each case the experiments were made with level surfaces.

3. *The storm or flood water* varies according to the absorbent power of the ground over which it flows, together with the amount of evaporation. It either flows off the surface to form streams and rivers, which supply many towns, such as London, York, and Chester, or it may be impounded in the head waters for the supply of towns at a distance. The average summer flow of water-sheds with rocks of medium absorbing power and steep slopes does not, as a rule, exceed 3·12 gallons per 1000 acres per second. In times of flood the flow off such water-sheds requires special precautions. Heavy rainfalls, causing excessive floods, have occurred

during the construction of reservoir dams, and are not by any means unusual: among others may be mentioned the following:—

Reservoir.	Owner.	Date.	Galls. per second per 1000 acres.	Rainfall per 24 hours (at the rate of).
				Inches.
Woodhead ...	Manchester Corporation	Oct., 1849	3125	12·
Rhodes Wood	" "	Feb., 1852	1562	5·96
Vyrnwy ...	Liverpool Corporation	Jan., 1883	1112	4·24
Vartry ...	Dublin Corporation ...	—	3202	12·22
Tansa ...	Bombay Corporation ...	—	4640	17·71

An inch of rainfall per 24 hours per 1000 acres is equivalent to 42·01 cubic feet, or 261,951 galls. per second.

1 in. per acre = 100 tons = 22,400 galls.

Although such extraordinary floods are of short duration, and occur at intervals of some years, yet the circumstances attending them must be taken into consideration in the design and construction of reservoir works, by providing means of passing such floods through the works without endangering them, and that such means of exit should be at all times clear, without the aid of manual or mechanical labour being required.

The average daily flow of some of the large rivers is given below—

	Per day.
River Thames at Ditton	906 million galls.
" Severn	300 " "
" Ouse, at York ...	140 " "
" Tiber (Italy) ...	5500 " "

To arrive at an accurate estimate of the quantity of water available in a catchment area, it is necessary to have rain-gauges fixed as previously stated, and recorded every day with simultaneous gaugings of the flow of water in the

streams and springs. Careful attention must be given to the stratification and dip of the rocks, as it is by no means an infrequent occurrence for a large portion of the rainfall to follow the dip of the strata and rise as springs in an adjoining water-shed. The gauging of the rainfall, streams, and springs, should extend over as long a period as possible, in order that the necessary calculations may be based on reliable data. The experiments and results given as to evaporation and percolation are instructive and interesting from a scientific point of view, but have been carried out on too limited a scale to be relied upon for the general purposes of water engineering.

CHAPTER X.

MEASUREMENT AND ESTIMATION OF THE FLOW OF WATER.

The units of measurement usually adopted in gauging the flow of water, are the cubic foot and gallon for capacity, and a minute, second, or twenty-four hours for time.

An imperial gallon of water at a temperature of 62° Fahr. and a barometric pressure of 30 inches, weighs 10 lbs; and a cubic foot contains 6·235 (practically $6\frac{1}{4}$) gallons.

The flow of water through sluices, pipes, or channels, is governed by the same laws as falling bodies, and its motion would be uniformly accelerated but for the resistance offered by the friction and form of the channel.

The theoretical velocity due to the force of gravitation, friction being neglected, is expressed by the formula—

$$v = \sqrt{2gh}.$$

Where v = velocity in feet per second.

„ g = the force of gravitation, or the velocity acquired by a body falling through space under the influence of the attraction of the earth, in one second.

„ h = the head, vertical distance through which the water has fallen, or difference in level of the two ends of the channel, in feet.

The numerical value of g varies slightly according to the altitude and the latitude. In England the value usually adopted is 32·2 feet per second. The above formula may therefore be written—

$$v = 8{\cdot}025 \sqrt{h}.$$

If to the natural head artificial pressure equivalent to h′ feet has been added, then—

$$v = 8{\cdot}025 \sqrt{h + h'}.$$

These formulæ require modification according to the particular form of orifice through which water is discharged.

Gauging by means of an Orifice.

The discharge of water through an orifice is proportional to the area of the orifice and the mean velocity of discharge. Theoretically the discharge from an orifice should be equal to the product of the velocity of discharge and the area of the orifice. Experiment has shown, however, that the converging currents of water as they approach the aperture, produce a contraction in the area of the issuing stream, varying in degree according to the form of the orifice. This is called the *vena contracta*. A coefficient, determined by experiment, has therefore to be applied in each case, so as to make allowance for this contraction.

The formula for discharge through an orifice may therefore be written—

$$q = 8{\cdot}025\, c\, a \sqrt{h}.$$

Where q = discharge in cubic feet per second.
„ a = area of orifice in square feet.
„ h = head in feet, or the height of the surface of the water above the centre of the orifice.
„ c = a coefficient applicable to the particular form of orifice.

The following values for c are adapted from those given in Spon's Engineering Tables :—

Round or square orifices in a thin plate, ·62.

Sluice at end of a rectangular channel, ·70.

Short tubes (three diameters and under) with square edges, ·81.

Short tubes when the tube projects into a reservoir or cistern, ·71.

The following table give the results of experiments made

by eminent observers upon circular orifices, with sharp inner edges:—

Name.	Head.	Diameter of orifice.	Coefficient.
	Feet.	Inches.	
Abbé Bossut	0·6	1·0	0·649
Castel	2·7	1·2	0·629
Venturi	2·9	1·6	0·622
Rennie	1·0	1·0	0·633
Rennie	2·0	1·0	0·619
Eytelwein	2·4	1·0	0·618
Weisbach	2·0	1·2	0·614

Mr. Mair Rumley, in his experiments at Messrs. Simpson and Co.'s works at Pimlico, recorded in the "Proceedings" of the Institution of Civil Engineers, found that the coefficient of discharge was affected by the temperature of the water.

The discharge through a submerged orifice is calculated in exactly the same manner, except that the difference in level of the surface of the water on either side of the orifice is taken as the head.

Gauging by means of Weirs.

For this purpose a sharp-edged weir (Figs. 14 and 15) gives the most satisfactory results. A still-water pond should be formed on the up-stream side of the weir, to steady the flow of the water. A peg should be driven at a point in this pond as far as possible from the weir, and the upper surface of the peg should be made perfectly level with the upper edge of the weir. As it is difficult to drive a peg with precision under water, especially when the bottom of the pond is hard and stony, the following is a useful practice: Drive the peg so that its upper surface is slightly below the required level, and then drive a long flat-headed nail into the top of the peg. By means of a hammer the nail may be easily driven until its head is exactly level with the upper surface, or sill, of the weir.

To construct a weir for the purpose of ascertaining the discharge of a stream of water, a water-tight dam must be

formed, the best material for which is clay. In this dam the weir is fixed, which usually consists of a plank or frame

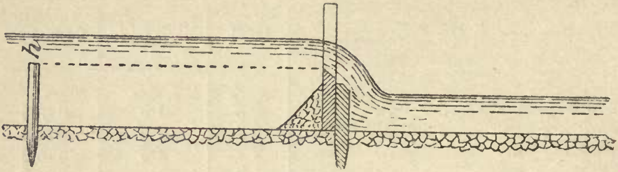


Fig. 14.

of wood, with a rectangular notch cut in its upper edge. The plank is kept in a vertical position by means of stakes driven on either side of it. The horizontal edge of the notch over which the water flows, must be fixed perfectly level, and must be bevelled so as to present a thin edge on the up-stream side. The depth of the water below the

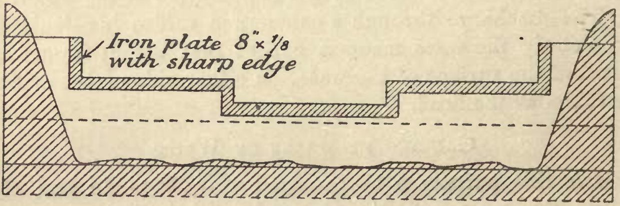


Fig. 15.

sill of the weir on the up-stream side should not be less than three times the depth of the water flowing over the weir; and the difference in level between the surface of the water on the down-stream side of the weir and the sill of the weir should not be less than half the maximum depth of the water flowing over the weir.

The theoretical formula for the discharge of water through rectangular notches is—

$$Q = \frac{2}{3}\, l \sqrt{(2\, g)}\, H^{\frac{3}{2}}$$

Where l = length of notch in feet.

H = height in feet of the free-level of the discharging water above the sill.

Q = discharge over weir in cubic feet per second.

Owing to the interference with the free flow of the stream occasioned by the ends and sill of the notch, a coefficient, c, has to be applied to this equation, bringing it to the form—

$$Q = \frac{2}{3} cl \sqrt{(2g)} H^{\frac{3}{2}}$$

The coefficient c varies with l and H.

With values of H between ·25 and 2, and with l not less than 2, the coefficient c is fairly constant, and may be taken as ·62, which is the same as that for the discharge of water through round or square orifices in a thin plate, given above.

In cases where extreme accuracy is not required, the following formula, proposed by the late Mr. Thomas Hawksley, F.R.S., may be employed :—

$$Q' = \frac{lh\sqrt{h}}{2}$$

Where Q' = discharge over weir in gallons per second.
„ h = depth of water flowing over weir in inches.
„ l = length of notch in feet.

The table given on p. 66 has been calculated from this formula.

All measurements of depth should be taken at the peg above referred to, which should be situated at least 3 feet above the weir. A thin steel rule should be used for this purpose.

Where, however, only the approximate discharge is required, the measurement may be taken over the sill of the weir. This method will obviously give a low discharge.

Gauging by means of Uniform Channels.

The calculation of the discharge by uniform channels, such as canals and bye-washes, is of great importance in waterworks engineering, and has received much attention.

At the commencement of this chapter it was stated that the flow of water through sluice-pipes or channels is governed by the same laws as falling bodies, and its motion would be uniformly accelerated but for the resistance offered

DISCHARGE IN GALLONS PER TWENTY-FOUR HOURS FOR EACH FOOT IN WIDTH OF SILL.

Head of Water.	Decimals of an inch.										Head of Water.
Inches.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Inches.
0	—	1365	3863	7098	10,927	15,273	20,075	25,298	30,910	36,881	0
1	43,200	49,838	56,785	64,028	71,559	79,360	87,429	95,751	104,322	113,139	1
2	122,186	131,462	140,963	150,679	160,610	170,758	181,104	191,651	202,402	213,339	2
3	224,467	235,779	247,283	258,960	270,832	282,864	295,068	307,452	319,997	332,714	3
4	345,600	358,632	371,824	385,191	398,711	412,380	426,194	440,170	454,284	468,553	4
5	482,976	497,548	512,216	527,088	542,072	557,219	572,479	587,971	603,423	619,078	5
6	634,884	650,788	666,894	683,094	699,439	715,899	732,473	749,186	766,008	782,966	6

by the friction and form of the channel. The principal part of the friction is proportional to the square of the velocity, and is nearly the same at all depths. The friction, however, varies according to the surface of the fluid exposed to the solid in contact therewith, in proportion to the whole quantity of fluid; that is, the friction for any given quantity of water is as the surface of the bottom and sides of a river directly, and as the whole quantity of water in the river inversely. Therefore, supposing the whole quantity of water to be spread on a horizontal surface equal to the bottom and sides, the friction is inversely as the height at which the river would then stand, which is called the "hydraulic mean depth" (Eytelwein's "Hydraulics"). The hydraulic mean depth may be simply stated as the sectional area of a stream divided by its wetted perimeter.

Perhaps the most generally useful formula is that devised by Eytelwein, and slightly modified by Beardmore—

$$v = 55\sqrt{h \times 2f}$$

Where v = velocity in feet per minute.
,, h = hydraulic mean depth, in feet.
,, f = fall in feet per mile.

This formula must, however, be used with caution.

The following formula is given in Box's "Hydraulics" for long channels, neglecting head due to velocity of entry, which in long channels is inappreciable:—

$$C = \left(\frac{874520 \times F \times A}{L \times P}\right)^{\frac{1}{2}} \times A$$

Where L = length of channel in yards.
,, A = cross-sectional area of stream in square feet.
,, P = wetted perimeter.
,, F = fall in inches.
,, C = cubic feet discharged per minute.

Gauging by means of Surface Velocity.

The discharge of a stream may be found by observing the surface velocity by means of a wooden float or weighted tube. The time occupied by the float in passing over a

measured distance (which should be as great as possible) is noted, and the velocity reduced to lineal feet per second. As the surface velocity in the centre of a stream is greater than the mean velocity of the whole body of water, a proper allowance must be made.

The proportion which the mean velocity of the water in a stream of tolerably uniform section bears to the surface velocity at the centre has been made the subject of much investigation. The following formulæ, amongst others, have been proposed:—

U = Mean velocity in feet per second.

V = Surface velocity at centre in feet per second.

1. Prony—

$$U = \frac{V(V + 7{\cdot}783)}{V + 10{\cdot}345}$$

2. Neville (for velocities less than 10 feet per second, in small channels)—

$$U = {\cdot}816\,V.$$

3. Boileau (depth not exceeding 1 foot)—

$$U = {\cdot}785\,V \text{ to } {\cdot}865\,V.$$

4. Beardmore—

$$U = (V + 2{\cdot}5) - \sqrt{5V}$$

The discharge is found by multiplying the mean sectional area by the mean velocity of the stream.

On a large scale an instrument called a current-meter is frequently used to determine the velocity, and hence the discharge of a stream.

The results arrived at by the above methods are only to be adopted when more reliable data cannot be obtained.

Very small streams may be gauged by allowing the water to flow into a vessel of known capacity (*e.g.* a *pail* or *cistern*), and noting the time taken in filling.

MEMORANDA.

Cubit feet per minute—

$\times$ 9000 = gallons per 24 hours.

Gallons $\times$ 1604 = cubic feet.

Cubic feet $\times$ 6·25 = gallons.

CHAPTER XI.

PLANS, SECTIONS, LEVELLING, NECESSARY DATA.

Having investigated the available sources of suitable water in the neighbourhood of the district to be supplied, made careful gaugings, levellings, and obtained all possible information as to permanency of supply, compensation for water rights, probable demands for easements or purchase of land, and the nature of the ground with regard to excavation for reservoirs, laying mains, etc., it becomes necessary to embody or record the results obtained in the forms of plans, sections, and reports.

Water engineers have nowadays much to be thankful for in being able to obtain at a low cost the accurate surveys afforded by the Ordnance Department, instead of having to make special surveys for themselves—always tedious and often unnecessary. The Ordnance Surveys are issued on several scales, and can be obtained from Mr. Edward Stanford, Charing Cross, London, S.W., sole agent for England and Wales. The following information is extracted from a small pamphlet issued gratis by Mr. Stanford :—

1. $\frac{1}{500}$ (= 10·56 feet to a mile) for towns with population over 4000. Some towns have been published on the scales of $\frac{1}{528}$ (= 10 feet to a mile), and $\frac{1}{1056}$ (= 5 feet to a mile).

Each sheet represents 24 chains by 16 chains. Price, uncoloured, 2*s.* each ; coloured, 2*s.* 6*d.* to 10*s.* 6*d.*

2. $\frac{1}{2500}$ (= 25·344 inches to a mile). Each sheet represents $1\frac{1}{2}$ miles by 1 mile. Price, uncoloured, 2*s.* 6*d.* each (with areas printed on, 3*s.*) ; coloured, 2*s.* 6*d.* to 23*s.*

Approximately one square inch on these plans equals one acre.

The area of each enclosure, together with a reference number, is printed within it on the plan. The brace *S* on the plans indicates that the spaces so braced are included under the same reference number. Areas are computed to the centre of the fence or other boundary of the enclosure, except in the following cases:—

1. When the fence or other boundary is also the boundary of a parish or other civil division which does not follow the centre of the fence, the area is calculated to the parish or other boundary, and not to the centre.

2. The fences, etc., bounding either side of a railway are included wholly within its area.

Altitudes are given in feet above the approximate mean water at Liverpool. Those indicated thus ↑ B. M. 54·7 refer to marks made on buildings, walls, etc., and are called bench-marks. Trinity high-water mark, which is the level of the lower edge of a stone fixed in the face of the river wall on the east side of the Hermitage entrance of the London Docks, is 12·48 feet above Ordnance datum.

3. Six inches to the mile. Each sheet represents six miles by four miles. For certain counties quarter sheets, which are reductions of the $\frac{1}{2500}$ plans, may be obtained; these represent three miles by two miles. Price, full sheets, 2*s.* and 2*s.* 6*d.*, quarter sheets 1*s.* each.

4. One inch to the mile. Each sheet represents eighteen miles by twelve miles. Price (with one or two exceptions) 1*s.* each.

Before ordering plans an index map of the county, parish, or town in question should be obtained from Mr. Stanford. This will greatly facilitate the purchase, and save much delay and annoyance. It is generally best to have the sheets mounted on brown holland before they are sent. The charge is not heavy, and the results are excellent.

The $\frac{1}{2500}$th, commonly known as the 25 inches to the mile, scale is usually the most suitable for the general plan of a waterworks. Upon this plan the position of reservoirs

and pumping-stations, and the lines of mains and branches are marked, the dimensions of the pipes being figured above them. The positions of sluice-valves, air-valves, hydrants, etc., are also indicated. The names of the owners and occupiers of all lands upon which it is proposed to construct works or lay pipes should be written in the enclosures; and the names of owners and occupiers of mills, or other property in connection with which claims may be made as regards riparian rights, should also be entered against the property in question.

Careful levellings must be made along the proposed lines of pipes, and these should be plotted to the same horizontal scale as the general plan and to a vertical scale of 20 feet to the inch.

Detail plans and sections of reservoirs, pumping-stations, etc., should be drawn to a scale of not less than eight feet to an inch.

The hydraulic mean gradients should be drawn upon the sections of the main and branch pipes.

The following example will show the method of calculation by which the losses of head due to friction, and hence the hydraulic mean gradients, are found. Suppose the storage reservoir to be situated at A (Fig. 16) and that 8640 gallons per day are to be delivered at the point C, 11,520 at the point E, and 14,400 at the point F. The lengths of the main and branches are shown on the section; also the levels at each point.

As the demand during the summer is frequently greater than that in the winter, and the demand during the middle of the day much exceeds that of the remainder, it is usual to take three times the average rate of supply as the basis upon which the diameters of the mains and branches are calculated. Reducing the rate per day to gallons per minute, the system must be so designed as to enable 18, 24, and 30 gallons per minute to be discharged at the points C, E, and F, respectively, with the head available.

Assume a 4-inch pipe from A to B.

Assume a 3-inch pipe from B to D.

Assume a 2-inch pipe from D to F.

Draw the horizontal line AA′ through A and produce the ordinates through B, D, C, F, E, so as to cut AA′ at B′, D′, C′, F′, E, respectively.

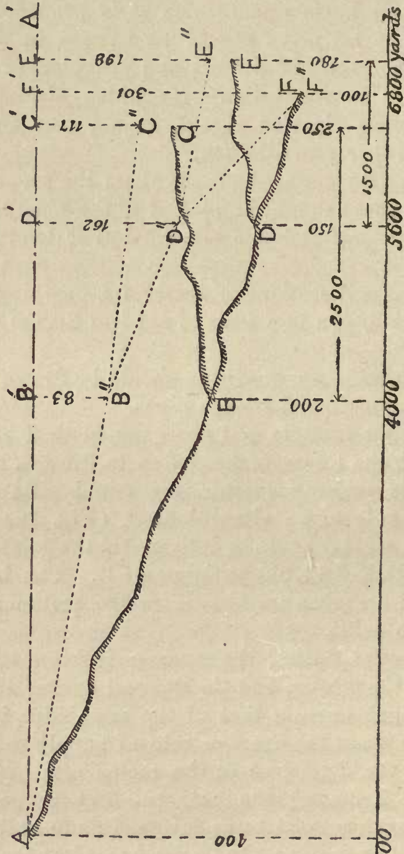


Fig. 16.

Then by the formula $G = \sqrt{\dfrac{(3d)^5 \times H}{L}}$ (or in practice by a set of tables), the loss of head due to the discharge of

—$18 + 24 + 30 = 72$ gallons per minute through the pipe AB is found to be 83 feet.

Make $B'B'' = 83$ feet and join AB''. Then AB'' is the hydraulic mean gradient for the section AB, provided that no point in the pipe AB rises above the line AB''.

In the same manner the loss of head due to the discharge of $24 + 30 = 54$ gallons per minute through the pipe BD is 79 feet. Make $D'D'' = 83 + 79 = 162$ feet, and join $B''D''$, which is the hydraulic mean gradient for the pipe BD.

Again the loss of head due to the discharge of 30 gallons per minute through the pipe DF = 139 feet. Make $F'F'' = 83 + 79 + 139 = 301$ and join $D''F''$, which is the hydraulic mean gradient for the pipe DF.

The point F is therefore only 1 foot above the hydraulic mean gradient at that point, and this may be neglected as insignificant. It now remains to determine the diameters of the branch pipes, BC and DE.

The head at the point B, or the distance of the hydraulic mean gradient above that point, being $400 - 200 - 83 = 117$ feet; and the point C being $250 - 200 = 50$ feet above the point B; the available head at the point C is $117 - 50 = 67$ feet. The diameter of a pipe 2500 yards in length to discharge 18 gallons per minute with a head of 67 feet is found from the same equation to be 2·184 inches.

A 2½-inch pipe (the commercial size next above 2·184) would therefore be used for this branch. The loss of head using a 2½-inch pipe, calculated in the same manner as in the previous cases, will be 34 feet. Make $C'C'' = 83 + 34 = 117$ feet, and join $B''C''$, which is the hydraulic mean gradient for the pipe BC.

The head at the point $D = 400 - 150 - 83 - 79 = 88$ feet; and as the point E is $180 - 150 = 30$ feet above the point D, the available head at the point $D = 88 - 30 = 58$ feet.

Calculating, as in the last paragraph, the diameter necessary to discharge 24 gallons per minute at the point E = 2·277 inches, a 2½-inch pipe would therefore be used for this branch also, and the loss of head for such a pipe would be 36 feet.

Make $E' E'' = 162 + 36 = 198$ feet, and join $D'' E''$, which is the hydraulic mean gradient for the pipe DE.

An examination of the section will now show that the pipes at no point rise above their respective hydraulic mean gradients, and that the latter are not situated unduly above the former.

The velocity of the water in these pipes necessary to obtain the specified discharges must now be calculated.

Let V = velocity in feet per second.

„ G = discharge in gallons per minute.

„ d = diameter of pipe in inches.

Then $V = \frac{G}{2\,d^2}$ (approximately).

From this formula the velocities may be calculated, and are tabulated as follows:—

Section.	Diameter of pipe in inches.	Discharge (gallons per minute).	Velocity (feet per second).
A to B	4	72	2
B to D	3	54	2
D to F	2	30	$3\frac{1}{2}$
B to C	$2\frac{1}{2}$	18	$1\frac{1}{2}$
D to E	$2\frac{1}{2}$	24	2

These velocities are below 3 feet per second (see p. 27), with the exception of the section D to F. It will be remembered that the point F was 1 foot below the hydraulic mean gradient. Taking both these circumstances into account, it would be advisable to increase the diameter of the pipe from D to F to $2\frac{1}{2}$ inches. This alteration will reduce the velocity in this section to $2\frac{1}{2}$ feet per second, and will raise the hydraulic mean gradient at F to 92 feet above it. The system may now be considered satisfactory.

Supposing that at any point the line of pipe had risen above its hydraulic mean gradient, then the pipes preceding that point would have to be enlarged to such an extent as would raise the hydraulic mean gradient above the pipe at

that point. As an alternative, the line of pipe may be lowered by means of a tunnel or deep cutting, but this is rarely economical or expedient.

In calculating the diameters of the various pipes necessary to afford a stated supply at a given point, the head required at the point to be supplied must be taken into account. Supposing the level of the source of supply to be 500 feet above a certain village, but that a head of 100 feet is required at the village itself, to force the water to the top stories of the houses, or for fire-extinguishing purposes, then the available head upon which the diameter of the pipe leading from the source to the village must be based will be only $500 - 100 = 400$ feet.

In calculating the diameters of the pipes from the maximum daily rate of supply, a certain minimum must be observed. For instance, a branch may be laid to supply a block of three cottages containing a population of 15 people. Allowing 10 gallons per day for each person, the average rate of flow to afford this supply would be ·104 gallons per minute. Trebling this for a maximum daily supply would give ·312 (or less than $\frac{1}{3}$ gallon per minute), and the time taken in filling an ordinary 3 gallon bucket would be nearly ten minutes. A system should be arranged so that a discharge at a rate of 3 gallons per minute may be obtained at each connection. At farm-houses, where the water is used for refrigerating the milk, a supply of at least 3 gallons per minute is required.

On the other hand, it is frequently necessary to lay down a branch main of considerably larger diameter than would be necessary to afford the requisite supply. As this often leads to waste of water (especially where the place to be supplied is isolated), which may interfere with the hydraulic mean gradients of the entire system, reduced fittings may be enforced, or the supply may be regulated by a sluice valve under the sole control of the undertakers, fixed at the termination of the branch. The following formulæ will enable the engineer to calculate the amount of reduction necessary :—

Let g = discharge in gallons per minute.
„ l = length of branch in yards.
„ d = diameter of branch in inches.
„ d_1 = internal diameter of tap in inches.
„ h = total head in feet.
„ h_1 = head consumed by friction in branch.
„ h_2 = head consumed by a screw-down tap fixed at the termination of the branch.

Then $h = h_1 + h_2$ and let $d_1 = r\,d$.

Then assuming that the obstruction to the flow of the water caused by the tap is the same as in the case of short tubes (not less in length than twice the diameter of the orifice), the area at the point of greatest contraction will be ·81, the area of the passage through the tap.

$$\text{Then (1) } h_1 = \frac{r^4 l}{1{\cdot}394d + r^4 l} \cdot h$$

$$\text{,, (2) } h_2 = \frac{1{\cdot}394d}{1{\cdot}394d + r^4 l} \cdot h$$

$$\text{,, (3) } g = \sqrt{\frac{(3d)^5 \times h}{l} \cdot \frac{r^4 l}{1{\cdot}394d + r^4 l}}$$

As the calculations from which the diameters of the mains and branches of a waterworks are obtained are based upon the results of the preceding levelling operations, a few words upon levelling may not be out of place. In the first instance, the engineer should never neglect to test his level before commencing work. The testing need not extend further than to prove that the level will "reverse" truly, and that the line of sight lies in the plane of collimation.

If, when the instrument has been set up, the bubble does not remain stationary in the middle of the tube on the level being revolved, the error must be rectified half by raising or lowering, as the case may require, the level by means of the capstan-headed screws, and half by the parallel plate-screws.

If, however, the level, after the most careful adjustment, refuses to reverse correctly, it should be sent to the makers.

In the meantime, the bubble should be centred at each reading by means of the plate-screws.

To adjust the level for collimation, select a fairly level piece of ground and measure out three chains, and place pieces of flat stone or slate for the staff to rest upon at the commencement and terminations. Call these ABCD. Set up the level at B and read the staff on A and C. This will give the true difference of level between A and C, as the errors of adjustment would be the same on either side, the distance being equal, and would neutralize each other. Then set up the level at D, and read the staff again on A and C. If, on comparing the last reading with the previous ones, the difference of level between A and C is the same in each case, the level is in adjustment. If, however, the second operation does not agree with the first, an error is present. This error is proportional to the length of the sight, and is, therefore (in the second operation), three times as great on A as on C; half the error in level being the error due to one chain in distance. This error must be corrected by raising or lowering, as the case may require, the cross-hair of the level by means of the collimating screws, until the readings of the staff when placed on A and C give the same difference of level whether the instrument be set up at B or D.

Always read each sight twice—the second time after booking. In turning the level on its axis, always turn it the way of the sun, otherwise it may become unscrewed, which would cause error and probably serious delay.

The necessary data include the following:—

Yield and permanency of source.

Quantitative analysis of water.

Sanitary survey of source.

Lengths of mains and branches.

Population to be supplied.

Rate of supply per head.

Levels.

Cross sections and particulars of streams, etc., to be crossed.

Additional supplies for trade, dairy, or compensation purposes.

Names of owners and occupiers, and rateable value of land to be interfered with.

Nature of ground to be excavated.

Quality of local building materials and labour.

Prices of manual labour and horse hire.

Facilities for transit.

Particulars as to quantities of water used for mills, etc., in connection with which claims may be made.

CHAPTER XII.

MATERIALS.

Amongst the principal materials employed in waterworks construction the following are included: Iron (cast and wrought), steel, copper, lead, zinc, tin, brass, gun-metal or bronze, stone, bricks, concrete, cement, lime, gravel, sand, clay, and wood.

Cast and wrought iron and steel are made from "pig-iron," which is manufactured from iron ore. Pig-iron is the name given to the crude, unpurified metal in the form that it is first obtained from the blast furnaces, and is classified as: (1) Bessemer; (2) foundry; (3) forge.

Bessemer "pig" is dark-grey, contains a large proportion of free carbon, a small quantity of silicon and manganese, and is practically free from sulphur and phosphorus. It is principally used for conversion into steel (Bessemer process). Foundry "pig" contains a large proportion of free carbon, and is therefore specially adapted for foundry work. Forge "pig" contains little free carbon, and is therefore adapted for conversion into wrought iron.

Cast-iron is obtained by re-melting foundry "pig"-iron in a small furnace termed a cupola. Inferior castings are sometimes run direct from the blast furnace. Cast-iron is sub-divided into: (1) grey; (2) white; (3) mottled.

Grey cast-iron is made from the best foundry pig, and produces the best castings. White cast-iron is made from forge-pig, and is only used for the most inferior descriptions of castings. Mottled cast-iron is a mixture of the grey and white varieties. If a little nitric acid be applied to a clean

fractured surface of cast-iron it will give a black stain with the grey variety and a brown stain with the white variety. White and mottled cast-iron do not rust so readily as the grey variety. Chilled castings are produced by using metal moulds.

Malleable cast-iron is produced by subsequently heating castings in an annealing oven with some substance containing an excess of oxygen. The oxygen combines with the carbon in the casting to a certain depth, depending upon the length of exposure, rendering that portion of the casting similar to wrought-iron.

Cast-iron contains a large percentage of carbon (from 2 per cent. to 6 per cent). It is chiefly used in waterworks construction in the manufacture of pipes, the bodies of sluice and other valves and appliances, in the heavy parts of engines and pumps, for roof-trusses, and for ironwork generally, which will not be subjected to tension.

Wrought-iron is generally prepared from forge-pig, by puddling, after which it is rolled and converted into "puddle-bars." The different qualities of "puddle-bars" are—

1. Puddled or rough bars.
2. Merchant bar, or common iron.
3. Best bar.
4. Best best bar.
5. Best best best bar.
6. Scrap bar; which is again subdivided into "best scrap," and "best best scrap."

Wrought-iron is practically free from carbon, and should not contain more than ·15 per cent. Wrought-iron is chiefly used in waterworks construction in the manufacture of tubes, for roof trusses, girders, and for ironwork exposed to tension, or where forging is necessary.

Steel is defined by Dr. Percy as "iron containing a small percentage of carbon, the alloy having the property of taking a temper." It contains from ·12 to 1·5 per cent. of carbon, and is, therefore, in composition, midway between cast and wrought-iron. Steel is manufactured in two ways—

1. By extracting a portion of its carbon from cast-iron (Sieman's process).

2. By adding carbon to wrought-iron (Bessemer process).

The principal varieties of steel are—

1. Blister steel.
2. Cast steel.
3. Mild steel.
4. Puddled steel.

Steel is chiefly used in waterworks construction for tubes, and largely in the manufacture of engines and pumps, for girders, and generally where high tensile strains have to be supported. The use of steel is rapidly superseding cast and wrought-iron for most engineering purposes.

Copper is principally employed for roses or strainers for pumps, or at outlets to reservoirs; also for floats for ball-taps, etc.

Lead is used for joining cast-iron pipes, for making distributing pipes, for weighting pump-valves.

Zinc is principally used for cisterns, covering roofs, and for covering iron to protect it from rusting (galvanizing).

All wrought-iron tubes used for distributing water should be galvanized. This is effected in the following manner. The iron is cleaned, and after being heated, is dipped in molten zinc, which forms a protecting coating without injuring the iron.

Tin is used for coating water-pipes internally, so as to protect them from the action of the water.

Brass is an alloy consisting of copper and zinc, in proportions varying from 2 to 18 of copper, to 1 of zinc. Brass is used for bushes and bearing surfaces, but is inferior to bronze. It is largely used for valves and taps.

Gun-metal or *Bronze* is an alloy of copper and tin.

Soft gun-metal contains 8 parts of tin to 92 of copper. Hard gun-metal, 18 parts of tin to 82 parts of copper. Bell-metal, 23½, or 23, parts of tin, to 76½, or 77, parts of copper.

Bronze is fusible, and makes good castings. It is soft, uniform in texture, and wears evenly, and is therefore specially suitable for bearing surfaces, producing little friction.

Its tenacity is high, and it does not corrode. It is extensively used for pump-barrels, valve-faces, slides, and screws, and also for making the best valves and taps.

The following table, taken from Unwin's "Machine Design," gives the safe limits of stress, with a live or varying load, to which most of the materials described above may be exposed:—

SAFE LIMIT IN POUNDS PER SQUARE INCH.

Material.	Tension.	Compression.	Shearing.
Cast-iron	3600	10,400	2700
Wrought-iron bars ...	10,400	10,400	7800
„ „ plates ...	10,000	10,000	7800
Soft steel, untempered	17,700	17,700	13,000
Cast steel „ ...	52,000	52,000	38,500
Copper	3600	3120	2300
Brass	3600	—	2700
Gun-metal (or bronze) ...	3120	—	2400

Stone is used in waterworks construction, in building the walls of reservoirs and filter-beds, in the erection of engine and pumping houses, and as a constituent of concrete. Except, however, where stone is plentiful and easily worked, masonry is generally superseded by brickwork or concrete. Any hard stone may be used for concrete, though limestone perhaps gives the best results.

Bricks are almost indispensable in waterworks construction, for the purposes mentioned above in connection with stone, and often form a heavy item of expense.

The best quality of bricks should be used, especially for outside work. The cost of these is, however, frequently prohibitive, and then the local productions, if there are any, must be carefully inspected by the engineer. Economy only begins when efficiency has been attained; but the efficiency of a material depends upon what is required of it. The varieties of bricks depending upon the materials used and the subsequent manipulation are almost endless. For

general work, however, the variety known as "stocks" will be suitable. These are hard-burned bricks, well-shaped and sound. Staffordshire blue-bricks are best for coping purposes. Good bricks should be sound, free from cracks and flaws, stones and lumps of any kind (especially lime). They should be regular in shape, uniform in size; their arrises or edges should be square, straight and sharply defined; their surfaces should be even, not hollow, and not too smooth. They should not absorb more than one-sixth of their weight of water. They should be hard, and burnt so thoroughly that there is incipient vitrifaction throughout. They should give out a ringing sound when struck against one another. The cost of brickwork is calculated by the rod or by the cubic yard. A rod of reduced brickwork consists of 272 superficial feet, one and a half bricks in thickness, and is equal to $11\frac{1}{3}$ cubic yards. The following estimate of the cost of brickwork for a small reservoir may be useful as indicating the points to be included.

Cost of Brickwork per Cubic Yard.

	s.	*d.*	*s.*	*d.*
400 stock bricks at 30*s.* per 1000	12	0		
Cartage	3	0		
			15	0
1 to 4 { $1\frac{1}{3}$ bushel Portland cement at 3*s.* 9*d.* ...	5	0		
1 to 4 { $5\frac{1}{3}$ bushels sand at 1*s.* $1\frac{1}{2}$*d.*	6	0		
			11	0
Labour—				
Bricklayer: 5 hours at 6*d.*	2	6		
Labourer: 5 hours at $3\frac{1}{2}$*d.*	1	$5\frac{1}{2}$		
			3	$11\frac{1}{2}$
			£1 9	$11\frac{1}{2}$

Say 30*s.* per cubic yard.

In this instance the bricks were obtained from a local brickyard, and were of inferior quality, but good enough for the work. A thoroughly good class of bricks would have cost 66*s.* per thousand, including railway carriage and extra haulage. The Portland cement cost 10*s.* 2*d.* per cask, less 3*s.* for returned empties, or 43*s.* per ton nett, on rail in

London. There was no local sand suitable for mixing with cement. The sand estimated for was sea-sand, costing 4*s.* per ton on rail, and to this had to be added heavy railway carriage and haulage.

Brickwork in reservoirs should always be laid in Portland Cement or the best hydraulic lime.

Concrete is extensively used in waterworks construction, both for foundations and for entire structures. The materials for concrete are: (1) The aggregate or body. (2) The matrix or mortar.

The aggregate may consist of broken stone, slag, bits of brick, or almost any hard material. It should be broken to about a $2\frac{1}{2}$-inch gauge. The matrix is either lime or cement and sand. The proportions in which the aggregate and matrix are taken should depend upon the proportion of void to solid in the former. This can be found out by filling a water-tight box of known capacity with the aggregate, and then noting the quantity of water that can be poured into the box without overflowing.

One cubic yard of stone, broken to $2\frac{1}{2}$ inch gauge, contains 10 cubic feet voids; one cubic yard of ditto, broken to 2-inch gauge, contains $10\frac{2}{3}$ feet voids; one cubic yard of ditto, broken to $1\frac{1}{2}$ inch gauge, contains $11\frac{1}{3}$ cubic feet voids.

Shingle contains 9 cubic feet voids. Thames ballast (which contains the necessary sand), contains 4 cubic feet voids.

If the aggregate consists of stones of various sizes, the voids will be reduced. When the concrete is intended for foundations where strength is necessary and imperviousness is immaterial, the matrix may be slightly less than the voids. If, however, imperviousness is the first consideration the matrix must *exceed* the voids.

The following is an estimate of the cost of concrete for the work above referred to :—

Materials for 1 cubic yard of concrete (6 parts broken stone to 1 part of mortar): broken stone, 6 parts = 27 cubic feet; sand, 2 parts = 9 cubic feet; Portland cement, 1 part = 3·51 bushels.

PARTS OF A DAY OCCUPIED BY A BRICKLAYER'S LABOURER (HURST'S HANDBOOK)—

	Per cubic yard.
Measuring the materials	·04
Turning over twice	·06
Filling into barrows	·05
Wheeling, say 25 yards	·03
Levelling in layers	·02
Ramming	·03
	·23

ESTIMATE PER CUBIC YARD OF CONCRETE.

		s.	d.
Broken stone ($2\frac{1}{2}$-inch gauge), 27 cubic feet at 2*s.* 6*d.*		2	6
Sand, 9 cubic feet at 17*s.* 6*d.* per ton		7	$10\frac{1}{2}$
Portland cement, 3·51 bushels		13	2
Labour, ·23 days at 2*s.* 11*d.*		0	$8\frac{1}{2}$
	£1	4	3

The concrete should be mixed dry on a wooden platform, the materials being measured by means of wooden boxes without bottoms, turned over twice dry, sprinkled with sufficient water through a rose, turned over until thoroughly mixed, filled into wheelbarrows, wheeled to the site, tipped gently into position, and well rammed in 12-inch layers. One cubic yard is sufficient for one mixing.

Cement.—The cement most used in waterworks construction is Portland cement. It is used for making mortar, concrete, and for rendering.

The following estimate in connection with the reservoir above referred to for rendering may be useful. Cost per superficial yard of rendering on brickwork, $\frac{3}{4}$-inch thick, 1 of Portland cement to 2 of sand—

	s.	d.
Portland cement, ·21 bushel at 3*s.* 9*d.*		$9\frac{1}{2}$
Sand, ·42 at 1*s.* 1*d.*		$5\frac{1}{2}$
Plasterer and labourer, ·08 days at 14*s.* 7*d.* ...	1	2
	2	5

Portland Cement is grey in colour, weighs from 112 lbs.

per striked bushel, and should be ground so fine that after passing through a sieve containing 2500 meshes to the square inch, the residuum shall not exceed 10 per cent. Briquettes made from the cement and immersed in water, when sufficiently set, for seven days, should be capable of sustaining a tensile stress of at least 300 lbs. to the square inch.

Lime.—Hydraulic limes or limes capable of setting under water, are frequently used in waterworks construction, either alone or mixed with cement. The blue and brown Lias limes are examples. If of good quality, they give excellent results.

Gravel is used for filter-beds and for making concrete. In either case it must be clean and free from earth or vegetable matter.

Sand is used for filter-beds, and for mixing with cement and lime for mortar, and for making concrete. For filter-beds, the sand must be clean, uniform, but not too fine in grain, sharp, and approaching pure silica as closely as possible. For mortar and concrete the sand should be perfectly clean, free from clay or other impurities; the grains should be sharp and angular.

Clay is largely used for puddling. It should contain only a small proportion of sand, and should be quite free from vegetable matter, or friable stone; but the presence of a small amount of gravel gives it greater stability. The clay should be freed from all vegetable matter, and should be exposed to the weather or "weathered" for as long a period before use as possible. It should then be spread out flat, and cut across in every direction and thoroughly worked with spades, or passed through a pug-mill, sufficient water being added and the whole mass reduced to a stiff homogeneous consistency. It should then be rammed into position in very thin layers.

Wood is used in roof trusses, and in the construction of floors, doors, etc., in various parts of the work. It is also used for pile foundations. Oak, beech, and elm are the best suited for the latter purposes.

Innumerable tables have been published giving the relative strength of various materials to support loads. These strengths should never be approached in actual practice, and large margins should be allowed in designing structures from them. The following table of "Factors of Safety" is given in Unwin's "Machine Design."

	Dead load.	Live load.		
		In temporary structures.	In permanent structures.	In structures liable to shocks.
Wrought-iron ...	3	4	4 to 5	10
Cast-iron ...	3	4	5	10
Timber	—	4	10	—
Brickwork ...	—	—	6	—
Masonry ...	20	—	20 to 30	—

CHAPTER XIII.

STORAGE OF WATER.

One of the most important questions for the water engineer is the determination of the capacity for storage which is to be provided in the impounding reservoir. The purpose of these reservoirs is to maintain a balance between the fluctuations of supply and demand, when the rate of consumption is greater than the natural supply at the same period. They should not be too large or expensive, keeping in view the average growing necessities of the population. The average quantity of water required per head of population per day varies according to circumstances. It is generally supposed that it should not exceed twenty gallons in non-manufacturing, and thirty gallons in manufacturing towns; though, in fact, these quantities ought to be, and soon will be, regarded as maximum rather than minimum limits. The following table gives the variation in the quantity used in fifty-eight towns in the United Kingdom and in fourteen towns abroad. The comparison is not altogether satisfactory, as many of the towns abroad include water used for flushing purposes in the rate consumed per head:—

Table of Water Consumption per Head per Day in various Towns in 1892.

Town.	Galls. per head per day.	Town.	Galls. per head per day.
Aberdeen	60·0	Bath	21·5
Abingdon	5·0	Bedford	25·0
Banbury	17·0	Birmingham	23·0
Barrow-in-Furness ...	32·8	Blackburn...	27·2

Town.	Galls. per head per day.	Town.	Galls. per head per day.
Bolton	20·0	Leamington	17·0
Bournemouth	25·0	Leeds	30·0
Bradford	22·7	Lincoln	21·0
Bridgwater	16·0	London County	29·5
Burnley	22·09	East London	31·8
Cardiff	21·0	New River	28·5
Carlisle	22·0	Chelsea	34·6
Carnarvon	40·0	West Middlesex ...	29·2
Congleton	10·0	Grand Junction ...	33·3
Coventry	20·0	Vauxhall Southwark ...	31·2
Croydon	32·0	Lambeth	30·4
Dartmouth	12·0	Manchester	21·0
Darwen	27·0	Newport (Mon.)	20·0
Derby	20·0	Northampton	14·0
Doncaster	20·0	Nottingham	18·73
Dover	26·0	Oldham	20·0
Dublin	47·0	Perth	39·39
Dundee	50·0	Ripon	23·0
Edinburgh	40·0	Salisbury	40·0
Glasgow	50·0	Sheffield	21·0
Halifax	23·75	Southampton	30·0
Hereford	30·0	Staleybridge	21·0
Huddersfield	22·5	Stratford-on-Avon ...	19·5
Keighley	30·0	Ulverston	40·0
Lanark	40·0	Warrington	20·0

TABLE OF WATER CONSUMPTION PER HEAD PER DAY IN FOREIGN TOWNS IN 1892.

Town.	Galls. per head per day.	Town.	Galls. per head per day.
Bayonne	55·0	Kiel	28·0
Berlin	22·9	Limoges	52·8
Bonn	63·0	Magdeburg	29·7
Boston, U.S.A.	76·0	Marseilles	99·0
Chicago	95·0	New York	65·0
Detroit	126·0	Paris	47·0
Frankfort	39·0	Philadelphia	56·0
Hamburg	52·0	Stuttgart	23·8

The consumption having been estimated according to the circumstances existing in the area to be supplied, the rainfall within the proposed catchment basin is then to be determined. In estimating the storage required, the data afforded by any single or average year will not be sufficient. The estimate must be based on a period of years during

which the rainfall is below the average. There are several methods for determining the capacity of storage required, some by empirical formulæ, others by graphical methods. Extreme care should be taken in adopting empirical formulæ that due consideration is paid to the geological and other conditions existing within the catchment area to be dealt with. The late Mr. Thomas Hawkesley, F.R.S., deduced the following formula based upon his extensive experience—

$$z = \frac{1000}{\sqrt{r}}$$

Where z = the number of days' storage required (which varies from 100 to 250 days).

„ r = average rainfall in inches during three consecutive dry years, the average rainfall for a dry year being taken at five-sixths of that for an average rainfall of a long series of years.

A graphical method was communicated to the Liverpool Engineering Society, in December, 1891, by Mr. T. Turner Tudsbury, and a further paper was recently read before the Austrian Society of Civil Engineers, by Herr W. Rippl, of which the following is a description:—

On an axis of abscissæ, the months are laid off for each year of the period under consideration, and the demand of the town in cubic feet or gallons for each month plotted as ordinates, a slightly undulating curve drawn through the points so plotted gives the demand curve. In a similar way the supply curve is plotted, and represents the available rainfall from the water-shed.

Whenever the supply curve rises above the demand curve, we have a surplus on hand, and when the latter curve rises above the former a deficiency is shown for the period indicated. From such a diagram the surplus or deficiency for each month can be scaled off and used in the construction of a mass curve. The months and years of the period involved are represented by abscissæ as before; but the ordinate at each month represents the algebraic sum of all the surpluses and deficiencies from the beginning of the period to that

point. The mass curve reveals the surplus or deficiency during the interval between any two points on the axis of abscissæ, which is represented by the difference of the corresponding ordinates. An ascending curve shows an increasing, and a descending curve a decreasing storage; while crests and hollows show occasions when demand and supply are balanced.

Impounding or Storage Reservoirs.

The principal factors which determine the position of impounding reservoirs are—

1. Purity of source.
2. Area of catchment basin.
3. Quantity of available rainfall.
4. Altitude and suitability of site.
5. Geological structure.

1. Purity of source, which has been already referred to, is of paramount importance. The most satisfactory area to impound water is where there is a sparse population, scant herbage, and an entire absence of cultivated land. The nearer these conditions are approached, either naturally or artificially, by collecting and diverting the sources of pollution, the nearer will an ideal water-shed be realized.

2. Area of catchment basin is found by drawing a contour line from the proposed site of the embankment along the ridges which form the water-shed, or from which the water sheds itself on either side. This may be ascertained from a contoured Ordnance map, or by running a contour on the ground and marking it on the map. The land within this line is then measured to arrive at the superficial area.

3. Quantity of available rainfall has been already described.

4. Altitude and suitability of site. The height of the source above the highest point of supply can easily be ascertained by an inspection of an Ordnance map, and a simple calculation will determine the available head for

supply. The pressure in the district to be supplied should at all times be sufficient to force the water above the highest buildings, and for this purpose an average pressure of 80 to 100 feet would be ample, and meet all requirements. In exceptional cases the only available catchment area is not at a sufficient elevation to supply the district, and then the water has to be pumped from the impounding reservoir to another reservoir at a higher elevation. The greatest capacity with the least cost is the next object to be attained. Where a valley or lake can be utilized, the most economical method of forming a reservoir is to construct a dam at the inlet, the most desirable shape (Fig. 16A) being where the valley gradually

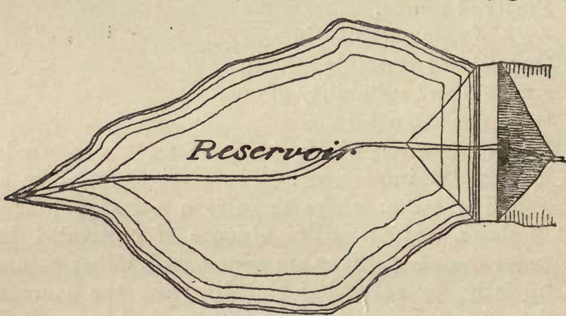


FIG. 16A.

widens out upwards from the dam with only a slight fall to it from the inlet. Such an arrangement would give the greatest capacity with the least cost for embankment, and the uniform depth resulting would prevent the growth of vegetation. Surface springs should be kept clear of the embankment on the inner side if possible, and if existing on the site of the outer portion, should be conveyed in pipes or concrete channels beyond the toe of the embankment. The materials of which the dam is to be formed will depend upon those which are available on the site of the dam, and will be dealt with in detail subsequently.

5. Geological structure of the area proposed to be utilized

for the formation of an impounding reservoir should be exceedingly carefully examined. Too much stress cannot be placed upon a thoroughly practical examination by an expert geologist or engineer who has a practical knowledge of the subject, as a want of sufficient care at the outset may result in a largely increased cost of construction, or even a subsequent abandonment of the site. The site of the Woodhead reservoir of the Manchester Corporation had to be abandoned on account of the unsatisfactory foundations revealed after the excavations had commenced. The presence of permeable rocks dipping towards the dam is a source of trouble, and every precaution should be taken to prevent the water from percolating into them. The best

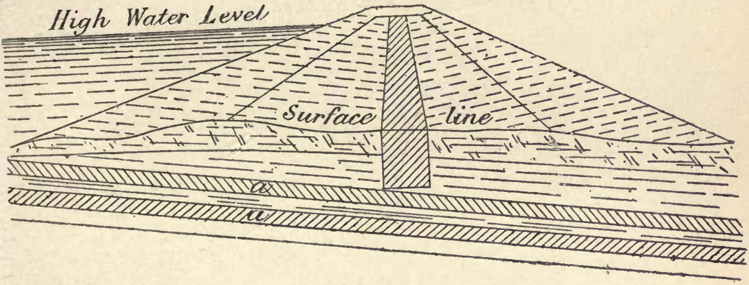


FIG. 17. *a*, Pervious beds.

method is to excavate to a sufficient depth along the outcrop, and afterwards to fill in the trench with puddle protected on the surface with concrete. The permeable strata should also be cut through by the puddle trench of the dam, or the water in the reservoir will gradually escape and rise as springs at a lower point in the valley, the quantity varying with the head of water in the reservoir (Fig. 17). Mr. Isaac Roberts, F.G.S., records the following observations upon the effect of pressure on the quantity of water that will pass through a square foot of sandstone of average coarseness, 10½ inches in thickness :—

Pressure.	Percolation.
10 lbs. per square inch	= $4\frac{1}{2}$ gallons.
20 „ „	= $7\frac{1}{2}$ „
46 „ „	= 19 „

The dislocations produced by faults, and the fissures proceeding from them, are also a fruitful source of anxiety. A knowledge of their positions can only be ascertained by trial pits systematically arranged; boreholes should not be relied upon. The fault may be practically an open fissure, as well as a dislocation of the strata, raising a permeable bed to or near the level of an impervious one (Fig. 18). The

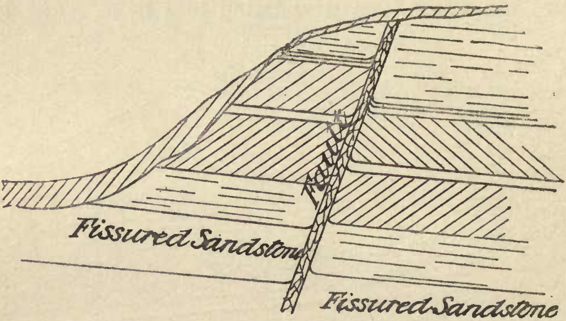


FIG. 18.

fissures extending on either side are even more difficult to deal with than the fault itself (Fig. 19); they frequently occur in the older rocks. The result of such fissures is to convey the water out of the reservoir either by the side of the dam or under it through permeable strata, where it may rise as springs. This entails a serious loss to the impounding works. In exceptional cases the matrix or material between the two cheeks of the fault is composed of fine silicious clay, which forms an effective dam in itself. The gorges forming outlets to valleys are frequently fissured, in many cases to such an extent as to render a site higher up the valley with a longer embankment preferable on the ground of economy

of construction. The puddle trenches in many instances have to be carried to a depth of 150 to 200 feet, owing to the fissures found in the neck or gorge of a valley, the site of which superficially possesses an exaggerated importance owing to the short length of embankment required. The economy in one direction is, however, far exceeded by the costly foundations in the other. As an instance of serious results arising from a fissured foundation, where due precautions have not been taken, we may refer to the Holmfirth reservoir, which burst in 1852, on the only occasion on

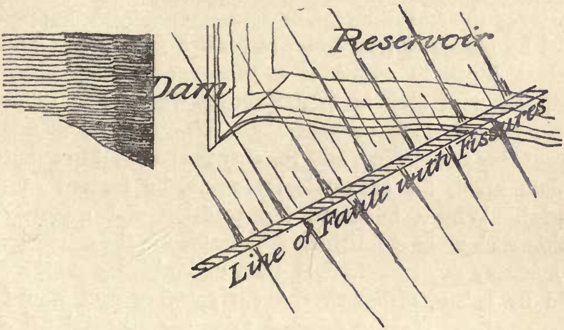


FIG. 19.

which it was filled. The embankment was constructed on fissured sandstone, and the water gradually escaped through the fissures, washing a portion of the embankment with it. Ultimately the embankment subsided below the weir-level, and a flood occurred completing its destruction.

CHAPTER XIV.

STORAGE OF WATER—*continued.*

The site of the embankment, or dam, having been thoroughly proved by means of trial holes at least 5 feet square, and of sufficient depth to admit of a proper examination of the strata, the next step is to determine whether it is to be constructed of earth or masonry. Where there is a good compact clay foundation, and the clay is abundant in quantity, the dam must, for economical reasons, be formed of that material. Where, however, the position and quantity of suitable rock make conditions favourable for the construction of a masonry or concrete dam, then undoubtedly such a dam would be better, although the comparative cost would be much greater. Having decided upon the material for construction, it must be disposed of in the design according to experience, the recognized laws of such structures, and the peculiar circumstances of the case.

Earthen embankments, as employed in the storage of water, consist, as a rule, of two trapezoidal-shaped figures formed of earth, clay, and stone, supporting a centre core of puddled clay, increasing in width directly as the depth (Fig. 17). The proportions of earthwork dams are limited by the angle of repose or slope at which the materials employed will stand. With cohesive materials this depends upon their power of absorbing water, which can best be found by experiment. Experiments upon several clays used in reservoir embankments show that the absorption by weight varies from 12 to 53 per cent. In the latter case the embankment failed several times during construction.

In practice the outer slope should not be less than the ratio of $1\frac{1}{2}$ horizontal to 1 vertical, and, as a rule, it is made either 2 or $2\frac{1}{2}$ to 1. The inner slope, which has a greater tendency to slip, owing to its angle of stability being reduced by the water, should not be less than $2\frac{1}{2}$ horizontal to 1 vertical, and is more frequently made 3 to 1.

The total width of the bank at the level of the top of the puddle-wall should not be less than three times the width of the puddle at that level. This width from slope to slope varies from 10 feet to 30 feet.

The height of the embankment above high-water level varies according to circumstances. In numerous cases where the inner slope is continued up to the top of the embank-

FIG. 20.

ment (Fig. 20) a greater height is required to prevent the waves from being driven over the top of the embankment in stormy weather. The late Mr. T. Stevenson, P.R.S.E., gives the following formula founded on his experience as a harbour engineer for finding the height of the waves in violent squalls:—

$$H = 1{\cdot}5\sqrt{D} + (2{\cdot}5 - \sqrt[4]{D})$$

where H = the height of the waves in feet, where D = fetch in miles, which is the longest straight line that can be measured from any part of the dam to any part of the reservoir, when the latter is full and overflowing.

It is found to be more convenient to make the slope steeper above the water line with a storm-wall at its summit (Fig. 21), or to build a storm-wall entirely across the embankment at the high-water level, with a coping projecting at least 6 inches (Fig. 22). This has the effect of curving the waves back, and affords every protection to the top of the bank. The height of the top of the bank above the water in flat slopes should not be less than 8 feet vertical, and with

steeper slopes 5 feet vertical, with a dwarf wall at the water line not less than 4 feet vertical.

The width and batter or taper of the puddle-wall varies

FIG. 21.

with the materials of which it is composed. The clay used for the puddle should be carefully selected, and be of good

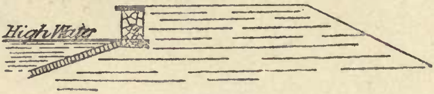


FIG. 22.

tenacious quality, comparatively free from sand, and entirely free from friable stones and vegetable matter. A small proportion of gravel is an advantage, and increases its stability. The clay should be turned over and weathered for two or three months, and then well cut, tempered, and worked in stages, and afterwards passed through pug-mills. It is then conveyed to the trench and inserted in layers. The top width of the puddle wall varies from 3 feet to 10 feet, and tapers outwards at from 1 in 8 to 1 in 16 down to the surface level, where it is either keyed into a concrete shoe as a base (Fig. 23) or is continued down in a trench until a sound foundation and retentive material are reached. The trench puddle is frequently carried down at a reverse or inward batter at rates of 1 in 8 to 1 in 16, according to circumstances (Fig. 24). When the pervious strata extend to a considerable depth it may be necessary to carry the trench down vertically the full surface width of the puddle-wall. Where this is done the bottom of the trench is covered with a layer of cement concrete connected to a key-piece of the same material, the layer at the base being

12 inches or more in thickness. Where the strata are very porous or fissured, a wall of concrete, stone, or brickwork,

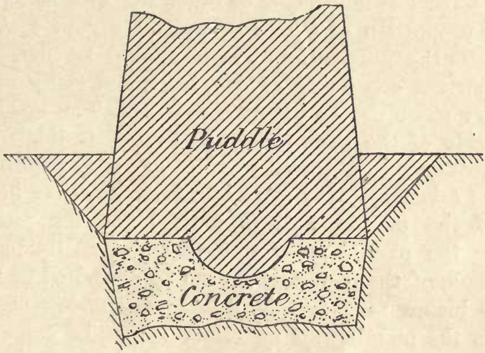


FIG. 23.

should be extended up the inner face of the trench as a protection to the puddle, and in some cases it is necessary

FIG. 24.

to use concrete in the trench instead of puddle. Water must in no case be in direct contact with the puddle.

The whole of the soil and earthy materials as well as

tree stumps and vegetation should be cleared off the site of the embankment, and no vegetable earth used in the construction of the inner bank. The materials in the inner portion should consist of fine clayey or other adhesive material with a small proportion of stones or ballast, except towards the toe, where the proportion of stone should be increased, the outer portion consisting of dry, hard, and stony materials, with dry stone drains where necessary. The materials on either side of the bank should be well consolidated as the work proceeds. On either side of the puddle-wall a width of selected clayey material of not less than four times that of the puddle wall is formed for the purpose of keeping the puddle moist, and to assist in its protection. The whole of the materials should be deposited in layers of from 9 inches to 2 feet in thickness, curving or dipping towards the puddle-wall on either side. In some cases a bed of puddle is carried from the wall under the base of the inner slope and continued up the slope, sufficiently protected with selected material. The object of this is to render the inner bank impermeable (Fig. 25).

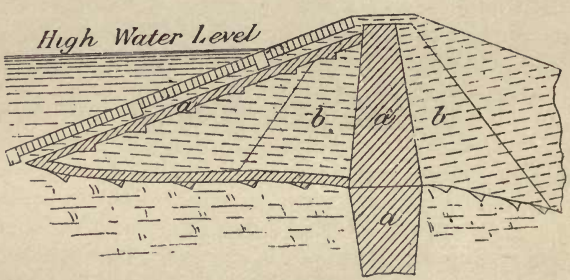


FIG. 25.
a, Puddle; *b*, selected material.

In excavating within the reservoir area for the purpose of providing material for the construction of the embankment, or with a view to increasing the capacity of the reservoir, care must be taken not to remove an impervious covering

over pervious strata, and thus create a difficulty which it should be the main object to avoid.

The inner slope should be protected with stone pitching over the entire area of the made embankment after it has become consolidated, the toe of this pitching being embedded in a concrete footing. The solid slopes, when of a clayey nature, are also usually pitched with stone for a vertical height of 3 feet above and at least 5 feet below the high-water line, as a protection from the wash of the waves, and as a preventative against the growth of vegetation in the shallow water, as well as against discoloration from the dissolved clayey matter.

In cases where a reservoir is constructed practically on a table-land and embanked all round, sufficient material is excavated from the interior to form the embankments and provide the requisite capacity. The methods of construction are in every way similar to the foregoing.

There are two indispensable accessories to an impounding reservoir, viz. the outlet and overflow weir, over which many difficulties have arisen and through which many disasters have occurred.

The outlet arrangements are carried out in several ways, according to the special circumstances of each case. The method of carrying the outlet pipes through the deep portion of the made embankment has been rarely followed, and is only permissible in shallow reservoirs. The terrible disaster in 1864, at the Bradfield or Dale Dyke Reservoir, near Sheffield, when 250 lives were lost, resulted from this practice. In reservoirs not exceeding 25 feet in depth a syphon (the action of which has already been explained), is the most economical and efficient as well as the safest method of drawing the water off. It does not interfere in any way with the embankment below the high-water line, and the same method has been recommended by Sir Robert Rawlinson for drawing off the lower water from large reservoirs (Fig. 26). This obviates the necessity of carrying the tunnel outlet at so low a level. The advantages of doing so are less interference with the strata at great depths and economy

in construction. The system generally adopted in large reservoirs is to cut a trench or drive a heading through the solid rock at one end of the embankment, and construct a

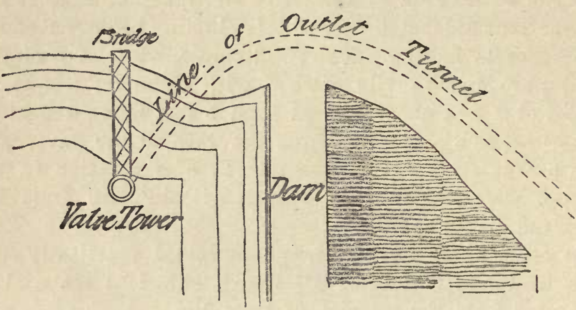


FIG. 26.

stone, brick, or concrete and iron culvert with a valve tower in the reservoir (Fig. 27). The base of the tower is below the deepest portion of the reservoir, unless a syphon is

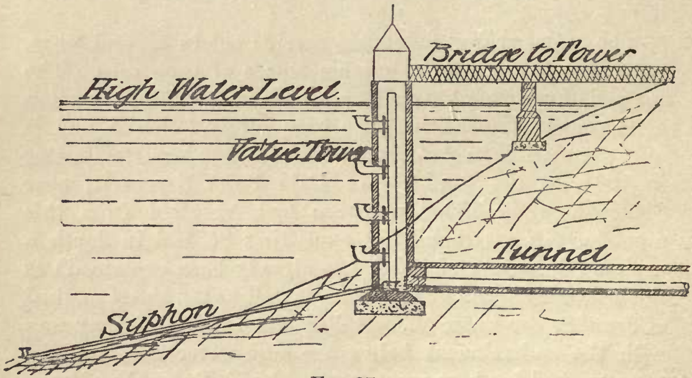


FIG. 27.

adopted and arranged to draw off the water at different levels. The water is discharged through the supply main laid within the culvert. The advantage of this system is

the facility with which any of the working parts can be examined and repaired without interfering with the embankment or being in any way a source of weakness to it. The question whether it is preferable to drive a heading or cut an open trench for the culvert depends upon the nature of the rock, apart from economical reasons. Where the rock is solid and compact a heading is preferable in most cases, but where the rock is fissured and contains many "backs," an open trench, which is filled in as the culvert progresses, is frequently the better course. This is due to the considerable difficulty attendant upon consolidating around the culvert in a timbered heading in fissured ground. In cases where it is necessary to cross the puddle-trench at a higher level than the bottom of the trench, the culvert should be

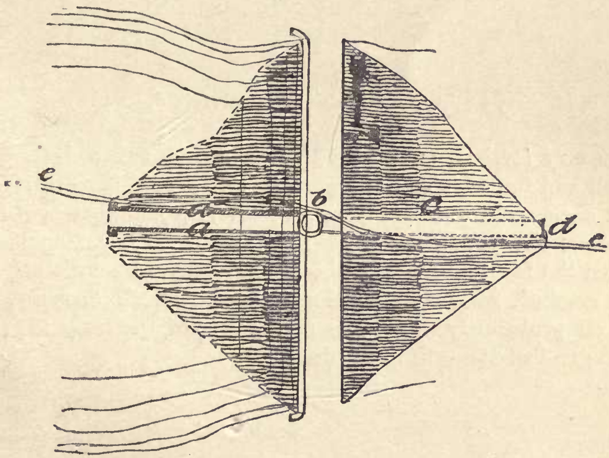


FIG. 28.

a, Wing walls; *b*, valve well; *c*, culvert; *d*, supply main; *e*, course of stream.

supported on a concrete pier brought up from the solid rock. The valve tower may either be constructed of stone, brick, or iron, with draw-off pipes at different levels, communicating

with a stand-pipe in the centre of the tower. Each draw-off pipe is controlled by a valve worked from the top of the tower, and the bell-mouths are turned upwards so as to admit of plugging from the surface in the event of anything going wrong with the valves within the tower.

The method represented by Figs. 28 and 29, is not a system to be recommended. Here the outlet is placed in the deepest part of the embankment, and consists of a

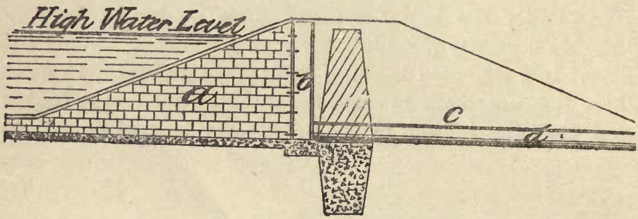


Fig. 29.

a, Masonry forebay; *b*, valve well; *c*, culvert; *d*, supply main.

masonry forebay, supported by iron struts, and a draw-off well and tunnel, also in masonry. The tunnel is supported on a concrete pier (with or without slip-joints), where it crosses the puddle-trench. This system is objectionable, from the fact that many of these tunnels have been distorted or cracked, frequently developing leaks. Such structures, in all probability, constitute an element of weakness where the greatest strength is required.

CHAPTER XV.

STORAGE OF WATER—*continued.*

The overflow or waste weir is placed at the embankment end of the reservoir on solid ground, with a concrete foundation. It consists of a heavy masonry base formed of large stones set in cement and well keyed together, with heavy pitching on the approach and discharge sides. The channel

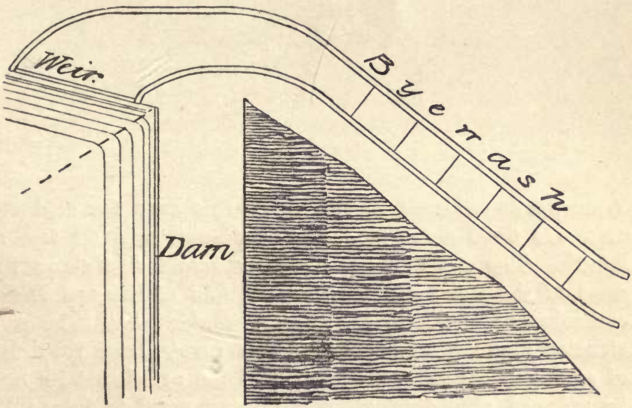


Fig. 30.

on the discharge side is continued in a series of steps down the side of the embankment (Figs. 30 and 31) (the water-course being pitched with stone), and terminates in the original stream-course of the valley clear of the embankment. The purpose of the overflow weir is to prevent the

water in the reservoir from rising above the level of the embankment and flowing over, and, in the case of earthen structures, causing the inevitable destruction of the works. In practice the length of the weir is made from $2\frac{1}{2}$ feet to 4 feet per 100 acres of water-shed. The length is limited by the maximum height to which the water is allowed to rise above the crest of the weir, which should never exceed 2 feet, and is generally fixed at 18 inches. The conditions peculiar to each gathering-ground must be taken into consideration in the design of such works, but the rules given above may be safely followed where no storm records are available. An instance of insufficient length of weir in connection with the Tittesworth reservoir of the Potteries

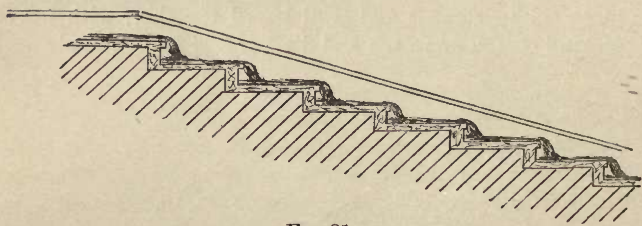


FIG. 31.

Waterworks occurred in 1862. In this case the drainage area was 6800 acres, and the waste-weir was 60 feet in length. The water in the reservoir rose 5 feet above the crest of the weir, and to within 1 foot of the top of the embankment. Where a bye-wash channel has been constructed round the margin of the reservoir, from the inlet, of sufficient capacity, the length of the overflow weir may be reduced accordingly. A residuum pond is frequently constructed at the inlet end of a storage reservoir, with considerable advantage. This has the effect of reducing the velocity of the storm waters, arresting any detritus, and allowing the water to deposit the greater part of the matter held in suspension. The last is a matter of some importance where the storm-waters are exceedingly turbid. The

pond is formed by constructing a wall or embankment across the mouth of the inlet, the top level of which being about 12 inches above the high-water level of the reservoir. In the case of an embankment it is necessary to face the top and slopes with heavy stone pitching or concrete. The inlet water is allowed to rise over the top of the residuum wall (which forms one long weir), and fall into the storage reservoir. The pond may be cleansed either by drawing off the water and removing the deposit by manual labour, or by means of pipes connected with the pond and continued through the reservoir to its outlet, delivering a continuous stream of sludge-water into the original river channel below the embankment.

The design and construction of masonry or concrete dams, being rarely necessary for rural supplies, do not come within the scope of this book.

The cost of storage reservoirs with earthen embankments varies considerably, according to circumstances, from £70 to £900 per million gallons of capacity.

Service reservoirs are supplied direct from the impounding reservoir, or, where filtration is necessary, from the filter-beds. Their office is to regulate the variation in the daily consumption, and to provide sufficient storage to meet the requirements of supply in the event of any accident of a temporary nature occurring between them and the source. The quantity of storage to be provided varies according to circumstances; but, as a rule, two days' storage will meet all emergencies. Where the source of supply is at a considerable distance, or somewhat inaccessible, and where there is a single main, or, in the case of a pumping supply, where there are no duplicate arrangements, it would be prudent to increase the storage capacity of the reservoir so as to make provision in the event of a breakdown.

In order to enable the student to form an idea as to the variation during the day, the accompanying diagram (Fig. 32) is given, which is taken from a Deacon differentiating meter. This diagram shows graphically the daily variation in a manufacturing town of 48,258 inhabitants,

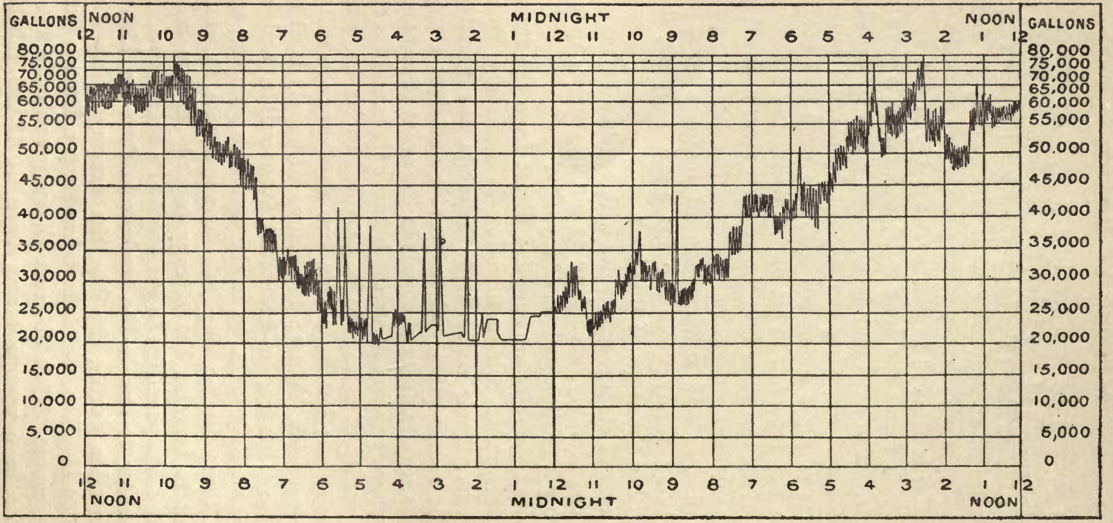

GALLONS
NOON
MIDNIGHT
NOON
GALLONS
12 11 10 9 8 7 6 5 4 3 2 1 12 11 10 9 8 7 6 5 4 3 2 1 12
80,000
75,000
70,000
65,000
60,000
55,000
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
12 11 10 9 8 7 6 5 4 3 2 1 12 11 10 9 8 7 6 5 4 3 2 1 12
NOON
MIDNIGHT
NOON

FIG. 32.

and may be taken as a fair example. The abrupt rises and falls shown on it between 2 a.m. and 6 a.m. are due to the supply to locomotives during those hours, the waste line or minimum flow being equal to 20,300 gallons per hour, which is chiefly due to defective fittings. The total consumption, including domestic and trade supply, per head of population is equal to 19·85 gallons, and the minimum flow 10·09 gallons per head, or practically one-half of the supply.

The variations of supply during the different periods of the year are not so great as might be anticipated. The householder's favourite practice of allowing the taps to run during frosty weather, and the number of burst pipes, have the effect of raising the consumption in the town referred to frequently up to, and in excess of, the summer months. The following table gives the consumption per head per day for the last four years:—

GALLONS PER HEAD PER DAY.

Month.	1890.	1891.	1892.	1893.
January	19·77	29·30	23·26	28·50
February	19·57	23·26	21·24	23·43
March	20·38	21·54	22·53	22·75
April	18·95	20·38	23·11	23·14
May	20·99	21·06	23·39	22·11
June...	20·81	22·50	23·31	23·25
July	21·05	23·62	22·90	21·69
August	21·79	21·66	21·73	20·63
September	21·40	22·13	21·72	18·78
October	21·10	22·13	22·08	20·08
November	20·58	21·30	21·26	21·91
December	24·21	23·54	23·29	19·90

The site for a service reservoir should be at a sufficient elevation, and within the immediate vicinity of the district to be supplied. It is usually constructed either of masonry, brickwork, or concrete, and roofed over; or by excavation and embankments lined with concrete and pitching and left

open. It is absolutely necessary to cover the service reservoir when near a town or manufactories to prevent contamination, and especially so after filtration. Service reservoirs are only left uncovered when situated at some distance from any smoke or fumes from chemical or other works, and in such cases the depth must not be less than 10 feet, which may be increased with advantage so as to

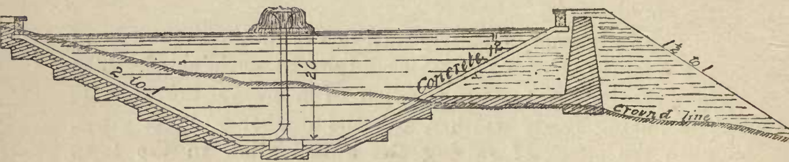


FIG. 33A.

prevent the growth of vegetable matter which produces that peculiar fish-like smell so common in shallow reservoirs. Figs. 33A and 33B are examples of open reservoirs, and Fig. 34 of a covered reservoir. Covered reservoirs should always have two feet of earth above the roof, to keep the water as cool as possible, and ventilators should be placed in the crowns of the arches. It is an advantage to have

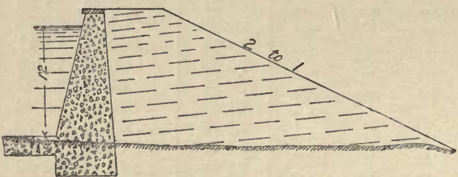


FIG. 33B.

a wall dividing the tank or reservoir into two portions for the purpose of cleansing from time to time.

Collecting tanks are used for storing the water from springs, and fulfil the offices of impounding reservoirs on a small scale, to which the duty of a service-tank is frequently added. These tanks are constructed of masonry, brickwork, or concrete, either with arched roofs, as in Fig.

34, or covered with iron plates supported by girders (Fig. 35).

The cost of covered service reservoirs varies from £2 to £6, and of open reservoirs from £1 per 1000 gallons.

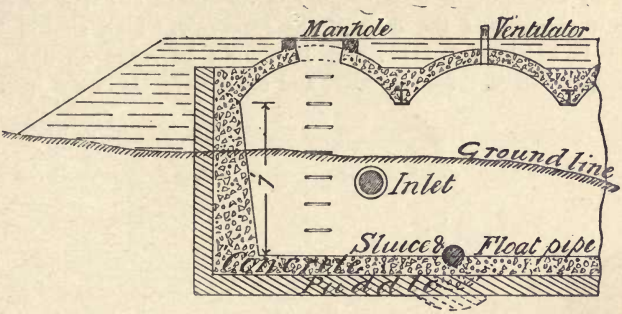


Fig. 34.

The usual accessories to a service or collecting reservoir, containing from 5000 galls. to 50,000 gallons, are the inlet and outlet, overflow and wash-out or scour-pipes. The inlet-pipe should be so arranged that the inflowing water may be shut off or diverted from the reservoir when the latter is being repaired, etc. The mouth of the inlet-pipe is usually fixed slightly above the level of overflow. The outlet should be a few inches above the level of the floor of the reservoir, so as to allow for a certain amount of deposit from the water. Its mouth should be covered with a perforated cap, rose, or strainer, which is best constructed of tinned copper. The outlet should be commanded by a sluice-valve, fixed inside the reservoir, worked from above by a wheel and spindle. The supply from a reservoir is sometimes taken by means of a floating pipe (Fig. 35). This ingenious method allows of the water being always taken from a little below the surface, which is the clearest portion of the water in a reservoir. The overflow pipe is either a pipe taken through the wall of the reservoir, with its mouth at the highest point to which the water is to be allowed to rise, or it may consist of a vertical pipe carried

up from the floor of the reservoir, having a bell-mouth for receiving the overflow water, and an inlet at the base controlled by a valve which acts as a scour or wash-out pipe. In the latter case the pipe should be constructed of copper. The wash-out, or scour-pipe, has its mouth situated at the lowest point of the floor of the reservoir, which should be made to slope towards it. It should be large enough to empty the reservoir rapidly, and must have its outlet below

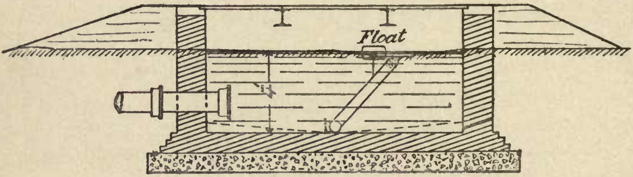


FIG. 35.

the level of the floor of the reservoir. It may either be controlled by a sluice-valve worked from the surface, or in small tanks by means of a brass plug and chain. In small tanks the overflow and wash-out are sometimes combined, the foot of the vertical overflow pipe being ground into the mouth of the wash-out; by loosening and lifting the overflow pipe the water is free to escape through the wash-out. Ladder-irons should be built into the wall of the reservoir to allow of access to the interior.

The inner surface of the reservoir should be rendered with cement, which should be brought to a perfectly smooth surface with the trowel.

Where the supply is obtained from springs, it is usually necessary to collect them by means of stone-ware pipes with open joints covered with broken stone. These pipes are connected by means of close-jointed pipes, and conveyed to a small tank, from whence they are conducted to the reservoir. Great care must be taken in collecting springs, to avoid all chance of pollution.

CHAPTER XVI.

THE PURIFICATION OF WATER—FILTRATION.

The methods of "purifying" or rendering water suitable for domestic consumption are aëration, subsidence, precipitation, straining, and filtration.

Aëration is a natural process of oxidation, the atmosphere acting on matter in solution, this action being facilitated by forming cascades and fountains to agitate and break up the water into thin sheets and spray. This method is employed by the West Gloucester Water Company, at Frampton Cotterill, to get rid of the large amount of dissolved sulphuretted hydrogen contained in the water, which by this means is rendered bright and more palatable. Exposure to the atmosphere has the effect of softening hard waters by releasing the loosely combined carbonic acid and precipitating the carbonate of lime, but in such cases there is great liability to develop vegetable growth. The beneficial effects of aëration through the use of fountain inlets in destroying algæ have been proved—in two instances with remarkable results. The action of the atmosphere on running streams in rivers and channels is well known, the organic impurities being brought in contact with the oxygen of the atmosphere, and gradually oxydized and rendered innocuous.

Subsidence is a process of settlement or gravitation of matter held in suspension, its rapidity depending on the specific gravity or fineness of the matter to be deposited. This action is continually proceeding in storage reservoirs to a greater or less extent, according to the condition of the

water, as well as in the settling ponds, residuum lodges, and shallow reservoirs, which are specially adapted for the purpose, and are usually a preparatory stage for filtration.

Precipitation of certain impurities is produced by the addition of a precipitant, the most economical being caustic lime. A certain quantity of lime is added to a measured quantity of water in a tank, forming what is known as lime water; the clear liquid is drawn off by a float-pipe into another tank, and the water to be softened is added to it, the action being as follows: The caustic lime combines with the loosely combined carbonic acid in the water, forming carbonate of lime, which is precipitated along with the carbonates already in solution. The lime process was patented by Dr. Thomas Clarke, of Aberdeen, in 1841, and all the more recent methods are based on this principle. It has been successfully applied in several waterworks, both for domestic and manufacturing purposes, and among the towns using one or more of the recent methods may be mentioned Colne Valley, Southampton, Wellingborough, Saffron Walden, St. Helen's, and Stroud. The cost of softening, to the extent of removing from 10 to 24 degrees of hardness, varies from $\frac{1}{4}d.$ to $\frac{3}{4}d.$ per 1000 gallons. The hardness of water is stated in degrees, each degree representing one grain of carbonate of lime per gallon, and is found by noting the quantity of standard soap solution required to produce a permanent lather in a gallon of water. The composition of clear lime-water being constant, it is found that if the degrees of hardness are divided into 130 it will approximately give the number of gallons of the water which can be softened by one gallon of lime water. The above process has the great advantage of destroying organic matter and producing a bright effluent. The following table gives the hardness of water in a large number of towns:—

Name of town.	Degrees of hardness.	Name of town.	Degrees of hardness.
Glasgow (Loch Katrine)	0·80	Dundee	3·28
Manchester (Thirlmere)	1·50	Bournemouth	4·70
Sheffield	1·50	Worcester	8·06
Liverpool (Lake Vyrnwy)	3·15	Lowestoft	9·00

Name of town.	Degrees of hardness.	Name of town.	Degrees of hardness.
Newport (Mon.) ...	... 10·40	London	... 16·00
Cheltenham ...	... 11·56	Portsmouth ...	... 16·00
Yarmouth	... 12·60	Canterbury ...	... 17·00
Bristol	... 13·40	Stroud	... 17·00
Northwich... ...	... 13·60	Windsor	... 17·89
Nottingham ...	... 13·60	Southport	... 17·90
Newcastle-on-Tyne	... 14·00	York	... 18·00
Reading	... 14·50	Southampton ...	... 18·00
St. Helen's ...	... 15·00	Sunderland ...	... 24·00
Northampton ...	... 15·47	Wellingborough ...	... 37·00

The commercial and domestic economic advantages which a soft water possesses over a hard one are indisputable. The late Mr. Thomas Hawkesley, in recent evidence, however, stated that the death-rates for ten years, from 1882 to 1891, in twenty-seven large towns supplied with hard and soft water were: Hard-water supply, 20·2 per 1000 persons; and soft-water supply, 23·0 per 1000 persons = 13·9 per cent. excess over hard-water supplies.

Straining, *e.g.* through screens of brass or copper set in wooden frames—is absolutely necessary in all reservoirs. The screens intercept all floating and suspended matter larger than the mesh. They are removed from time to time for cleansing, which is usually performed by the application of a jet of water from a hose-pipe. The principle of filtration through sand, for the purpose of removing matters held in suspension, is often imperfectly apprehended, the popular idea being that the sand simply acts as a sieve, and prevents the passage of any particles larger than the interstices between the grains, at the same time allowing a certain amount of subsidence to take place upon the upper surfaces. The sand, however, does much more than this—the main action being due to the force of adhesion or mutual attraction between the particles in suspension and the whole surfaces of the grains of sand, and not the top surfaces only, as would be the case if the action were merely that of subsidence. It has also an effect, although small, on matters in solution, which is illustrated by the following analysis, by Dr. Percy Frankland, of river water before and after filtration:—

RESULTS OF ANALYSES EXPRESSED IN PARTS PER 100,000.

	Before filtration.	After sand filtration.
Total solid matters	28·40	26·20
Organic carbon	·123	·119
„ nitrogen	·025	·022
Ammonia	·0	·0
Nitrogen as nitrates and nitrites ..	·077	·089
Total combined nitrogen	·102	·111
Chlorine	1·6	1·6
Hardness, temporary	11·5	10·9
„ permanent	7·1	7·1
„ total	18·6	18·0

The fact that chemical analysis showed only a slight improvement in the water after sand-filtration somewhat threw discredit upon sand-filters, and it is only within the last few years, since the methods of Koch and others drew the attention of scientists to the bacteriological examination of water, that the remarkable efficiency attained by properly managed sand-filters in reducing the number of bacteria in water has been recognized. It was found that from 95 to 99 per cent. of the micro-organisms were removed by filtration from the London Water Company's supplies, reducing to a minimum the risk of pathogenic or disease-forming bacteria passing through the filters to the consumer. Dr. Percy Frankland has found that the water supplied to London after filtration contains less bacteria than many lake waters, a comparison of which is given as follows:—

New River (London), 38 colonies from 1 c.c. of water.

Grand Junction (London), 47 colonies from 1 c.c. of water.

Loch Katrine (Glasgow), 74 colonies from 1 c.c. of water.

Loch Lintrathen (Dundee), 161 colonies from 1 c.c. of water.

Lake Lucerne (Switzerland), 50 colonies from 1 c.c. of water.

Lake Geneva (Switzerland), 38 colonies from 1 c.c. of water.

Lake Constance (Switzerland), 58 colonies from 1 c.c. of water.

It would therefore appear that too much importance must not be attached to the number of bacteria present in drinking water, within certain limits, provided they are not of a pathogenic nature. The varieties of bacteria are very numerous, but most of these, with the exception of probably a few species, are beneficial rather than otherwise. Amongst the pathogenic bacteria that have been detected in water are the bacilli of tetanus, anthrax, typhoid, and the cholera spirillum. The advantages of sand filtration were strikingly illustrated at Hamburg and Altona during the cholera epidemic in 1892. These cities derive their supply from the river Elbe, the former without filtration, and the latter at a point in the river below the outfall sewers of both cities, but properly filtered, with the result that the relative proportion of cholera cases per 10,000 inhabitants was: Hamburg 290, and Altona 40 (of which many were imported cases).

A fact, which is receiving much attention from biologists at the present time, is that a filter-bed does not reach its normal state of efficiency, or technically "become ripe," until it has been in use five or six days; this is believed to be due to the formation on the surface of the sand of a gelatinous microbic tissue (zoogloea) produced by bacteria.

In the design of filter-beds many engineers take advantage of the site when on sloping ground to place the beds at different levels; others prefer to keep one level throughout by excavations and embankments. The area of each bed should be arranged so as to give an equal flow in the drains, but should not be excessive; and the distance for wheeling when the sand is being removed should not be too great. The number of beds should be sufficient to permit of half of them being out of use for cleansing purposes, the supply being maintained through the others. It is found convenient and economical to arrange the sand-washing apparatus in the centre of a battery of filter-beds. In some cases the washing apparatus is fixed in the centre of the bed, as at Belfast, but this arrangement is not generally adopted; another method, which is, without doubt, the proper one, is to

periodically reverse the filters and allow the water to flow upwards, and thus carry off the impurities through an over-

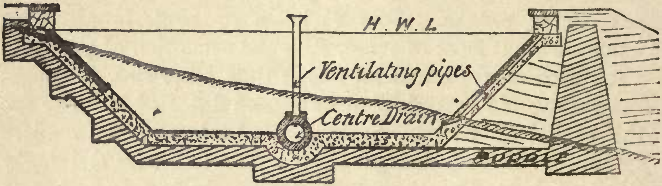


FIG. 36.

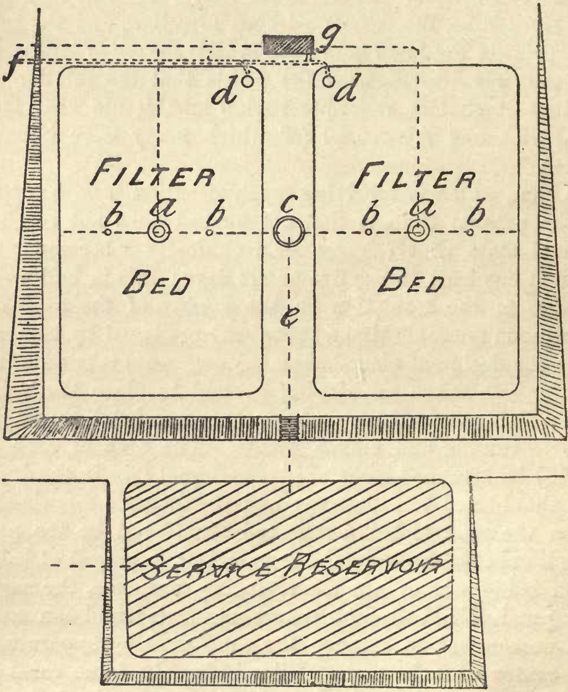


FIG. 37.

a, Inlet; *b*, ventilating pipes; *c*, valve well; *d*, overflow; *e*, filtered water main; *f*, overflow main; *g*, sand washer.

flow. Where this arrangement has been applied, the beds have attained their efficiency within twenty-four hours. The basin of the filter-bed is either constructed partly by means of excavation and embankment, with a puddle-wall

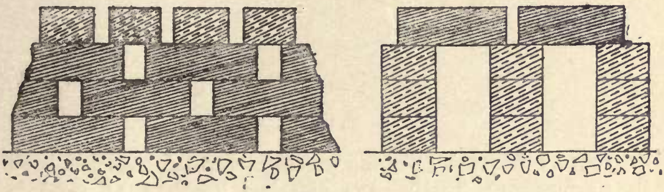


FIG. 38.

lined with concrete (Fig. 36), or with concrete walls backed up with earth (Fig. 33B, Chap. XV.). The floor of the basin is formed so as to dip towards the outlet of the filter, which communicates with a valve well, from which it is conveyed to a clear-water basin (Fig. 37). The centre

FIG. 39.

or main drain in the filter-basin is constructed of brick-work, concrete or perforated glazed pipes, and the side or arterial drains of perforated pipes or bricks laid dry with spaced joints (Figs. 38, 39, 40, 41). Ventilating pipes are carried up the slopes or side walls above the water-level

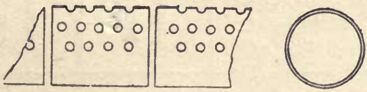


FIG. 40.

from each of the arterial drains, and from 2 to 4 on the line of main drain. The inlet is arranged in various ways. Fig. 42 shows an arrangement that has been adopted with great success.

The bed is formed of a layer of stone broken to pass through a 3½-inch. ring, but not through a 2½-inch. ring, and from 2 feet to 3 feet in thickness; this is succeeded by a layer of gravel 12 to 18 inches thick in two or three

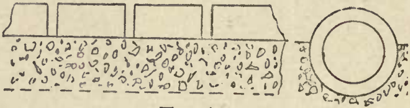


FIG. 41.

degrees of fineness, in some cases perforated tiles are used in preference; finally, the filtering medium of sand is spread over the whole of the supporting material (Fig. 45), the thickness varying at different works as shown in the following table:—

THICKNESS OF SAND-FILTERS.

	Maximum.		Minimum.	
	Ft.	Ins.	Ft.	Ins.
Chelsea, London	4	6	3	6
West Middlesex, London	3	3	2	6
Southwark, London ...	3	0	1	6
Grand Junction, London	2	0	1	3
Lambeth, London ...	3	0	2	6
New River, London ...	2	3	1	5
East London, London ...	2	0	1	4
Dublin	2	6	1	0
Bristol	2	0	1	0
Malvern	2	6	1	6
Harrogate...	2	0	1	0
Paisley	2	0	1	0
Barrow-in-Furness ...	2	0	1	0
Ulverston	2	0	1	0

Dr. Sims Woodhead, who has devoted considerable attention to the subject, suggests a minimum thickness of 3 feet. The sand for filtration should be hard and angular, and thoroughly washed, as well as the supporting material, before being deposited in the filter-basin. The rate of filtration should not exceed 5 inches per hour, or 2½ gallons

per hour per square foot. The mean rate of filtration in the London filters is less than $2\frac{1}{2}$ gallons per hour. The

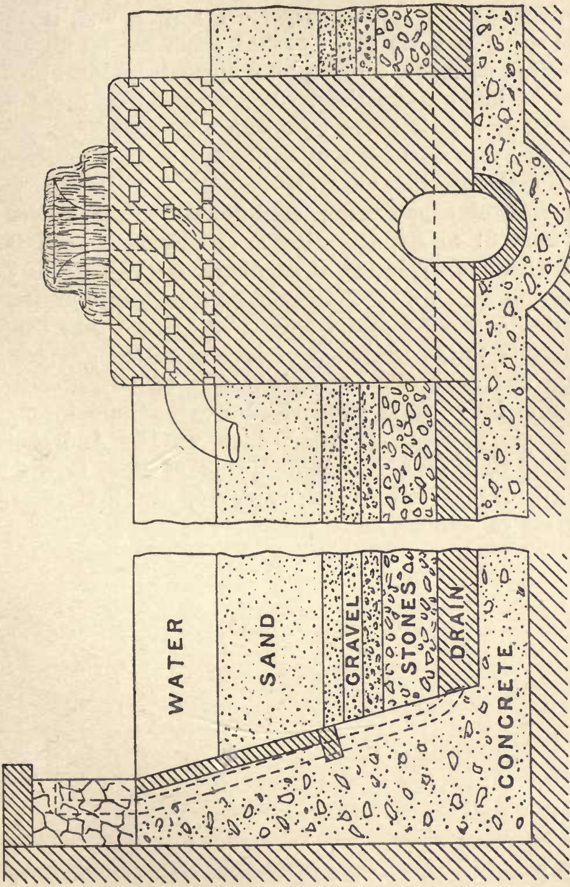


FIG. 42.

depth of water in a filter-bed in this country is usually from 2 feet to 3 feet, and from 4 feet to 7 feet where exposed to very low temperature, unless the beds are

covered over. The process of cleansing the filter-bed, where downward pressure only can be resorted to, is to remove a thin layer of sand half an inch or more in thickness, containing the perceptible suspended matter, and, if the sand is costly and has to be washed again for future use, to deposit it near the sand-washing apparatus, otherwise it is removed into a waste heap. The surface thus bared by the above process is raked over with a long pronged rake on two or three occasions, allowing a few days to elapse between each operation to aërate the sand.

The cost of constructing sand-filters per square yard varies from £1 to £4, according to circumstances, and the cost of filtration, exclusive of capital, is from 4*s.* 6*d.* to 7*s.* per million gallons. "Magnetic carbide," spongy iron, "polarite," and other media have been applied with beneficial results to the treatment of impure waters, producing a bright and pure effluent; and, in fact, with river waters the results fully justify the increased expenditure through their use. Mechanical filters, such as Dr. Anderson's Revolving Cylinders, containing oxide of iron, in a few cases where they have been employed, as at Hamburg, have given satisfactory results.

CHAPTER XVII.

PIPES.

WATER is conveyed in the various stages from the source to the consumer by means of open channels, tunnels, and culverts, or by pipes of cast- or wrought-iron, steel, lead, clay, and wood. Where the water is conveyed under pressure, pipes must be used, and they are generally more convenient and economical in construction. The thickness of the shell of the pipe and the form of joint depend upon the material employed, the capacity, and the pressure it will be required to withstand. In calculating the thickness of the shell, sufficient allowance must be made for imperfect workmanship, shocks in handling and laying in the trenches, also the weight of the superincumbent earth, and the traffic they will have to support, as well as the great strain which may come upon them on account of the sudden opening or closing of valves.

The bursting strength of pipes is found by the following formulæ:—

$$1.\ p = s \times \text{hyp log R}$$

$$2.\ s = \frac{p}{\text{hyp log R}}$$

$$3.\ \text{Hyp log R} = \frac{p}{s}$$

Where p = the internal pressure in tons per square inch.

" s = the maximum tensile stress in tons per square inch—7 tons being usually adopted as the value for cast-iron.

" R = the ratio of the outside diameter to the inside diameter.

A high factor of safety must be used to adequately allow for the strains imposed on the metal. Empirical formulæ based on practice are found to be more convenient for the purpose of determining the thickness of metal. These formulæ are numerous and widely divergent in their results, but the following, suggested by the late Mr. J. La Trobe Bateman, has been found to work well in practice:—

$$t = \cdot 25 + \frac{Hd}{9600}$$

Where $t =$ the thickness of the pipe in inches.
„ $H =$ the head of pressure in feet of water.
„ $d =$ the inside diameter of the pipe in inches.

The following table for cast-iron pipes has been calculated from this formula for a head of 300 feet of water pressure:—

Internal diameter.	Length (not including socket).	Thickness of metal. Inches and decimals.	Thickness of metal. Nearest thickness in 16ths of an inch.	Weight (including socket).	Bursting pressure per sq. in.	Factor of safety for 300 ft. = 130 lbs. per sq. in.	Weight of lead joints.
Ins.	Feet.			cwts.	lbs.		lbs.
2	6	·31	$\frac{5}{16}$	·418	4900	38	1·4
2½	6	·33	$\frac{3}{8}$	·625	3920	30	1·6
3	9	·35	$\frac{3}{8}$	1·06	3920	30	2·3
4	9	·375	$\frac{3}{8}$	1·38	2940	23	4·0
5	9	·41	$\frac{7}{16}$	2·01	2744	21	5·0
6	9	·45	$\frac{7}{16}$	2·38	2290	18	6·5
7	9	·47	$\frac{1}{2}$	3·17	2240	17	7·7
8	9	·50	$\frac{1}{2}$	3·59	1960	15	8·2
9	9	·53	$\frac{9}{16}$	4·55	1960	15	10·4
10	9	·56	$\frac{9}{16}$	5·03	1764	14	11·5
11	9	·59	$\frac{9}{16}$	5·51	1604	12	13·5
12	9	·62	$\frac{5}{8}$	6·69	1633	13	18·0

As absolute correctness cannot for practical reasons be obtained, it is usual to allow a deviation of 3 per cent. in the calculated weights.

Cast-iron pipes are connected by means of flange-joints bolted together, by spigot and socket joints run solid with lead, etc., or the spigot is turned and the socket bored out to

receive it. The flange-joint (Fig. 43) is stronger than either of the latter, but is more costly, and is rarely used when the pipes are laid horizontally in trenches, except for high pressures. It is chiefly used where the pipes are fixed

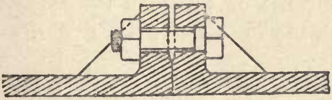


Fig. 43.

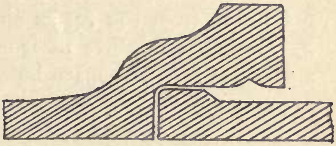


Fig. 44.

vertically for standpipes, etc. The faces are machined and jointed together with red-lead or with packing-rings made of lead, rubber, or other material.

The proportions of cast-iron flange-pipes are given in the following table:—

Diameter of pipes.	Diameter of flange.	Centre to centre of holes.	Thickness of flange.	No. of bolts in flange.	Diameter of bolts.
Inches.	Inches.	Inches.	Inch.		Inch.
2	6	$4\frac{3}{4}$	$\frac{3}{4}$	4	$\frac{1}{2}$
$2\frac{1}{2}$	$6\frac{1}{2}$	$5\frac{1}{8}$	$\frac{3}{4}$	4	$\frac{9}{16}$
3	7	$5\frac{3}{4}$	$\frac{13}{16}$	4	$\frac{9}{16}$
4	$8\frac{1}{2}$	$6\frac{3}{4}$	$\frac{7}{8}$	4	$\frac{9}{16}$
5	$9\frac{3}{4}$	8	$\frac{7}{8}$	6	$\frac{5}{8}$
6	11	$9\frac{1}{4}$	$\frac{7}{8}$	6	$\frac{5}{8}$
7	$12\frac{1}{2}$	$10\frac{1}{2}$	1	6	$\frac{5}{8}$
8	$13\frac{3}{8}$	$11\frac{1}{2}$	1	6	$\frac{3}{4}$
9	15	$12\frac{3}{4}$	1	8	$\frac{3}{4}$
10	16	$13\frac{3}{4}$	$1\frac{1}{16}$	8	$\frac{3}{4}$
11	$17\frac{1}{2}$	15	$1\frac{1}{8}$	8	$\frac{3}{4}$
12	$18\frac{1}{2}$	16	$1\frac{1}{8}$	10	$\frac{3}{4}$

Spigot and socket joints with lead, rust, rubber, or turned and bored joints take several forms. Fig. 44 is the joint adopted in the Tansa new works for supplying Bombay. Figs. 45A, 45B are frequently used, the former having the advantage of preventing blown joints, owing to the resistance offered by the bead on the spigot and the recess in the

socket. The socket space for jointing should not exceed $\frac{1}{4}$ inch in thickness in pipes up to 3 inches diameter, $\frac{5}{16}$ inch from 3 to 8" inches diameter, and $\frac{3}{8}$ inch from 8 to 12 inches diameter. Rust joints are rarely adopted for water-works, and when used under special circumstances they do not differ from the forms shown for lead. They are made by forcing a mixture of iron borings or turnings and sal-ammoniac into the space between the socket and the spigot.

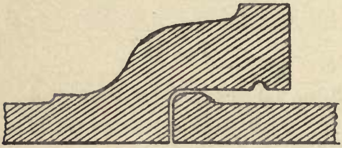


FIG. 45A.

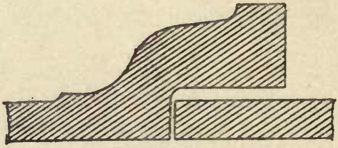


FIG. 45B.

Rubber joints (Fig. 46), known as Forster's patent, are largely used in the north of England. Two beads are cast on the spigot end, between which one or more circular rubber rings are placed and then driven into the socket. Turned and bored joints (Fig. 47) have been extensively used in the north of England and abroad, but only in a few instances in the south of England. Pipes jointed thus must

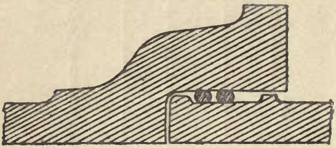


FIG. 46.

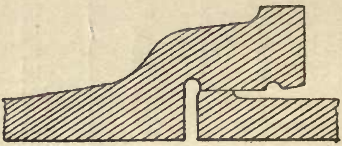


FIG. 47.

be laid in straight lines, with expansion joints or ordinary spigot and socket lead joints every tenth pipe, to allow for the variations in temperature. The half turned and bored is generally used, so that lead may be inserted if deemed necessary. The taper of the machined portion should not be more than 1 in 32, and the width should not exceed 1 inch. An increased width causes greater rigidity, rendering the work more liable to fracture by the traffic and super-

incumbent earth. Cast-iron pipes should be made from the grey variety, of good tough quality, which should be re-melted in a cupola before running. The increase in strength and density caused by re-melting is strikingly illustrated by the results recorded by Sir Frederick Bramwell with Acadian cold-blast iron, as follows:—

Samples.		Tensile strength per square inch.
1st samples	... ...	7·5 tons.
2nd "	after 2 hours longer fusion... ...	8·3 "
3rd "	" $1\frac{3}{4}$ " "	10·8 "
4th "	re-melted with fresh pigs	11·0 "
5th "	after 4 hours longer fusion... ...	18·5 "
Maximum of 5th samples...	... ...	19·6 "

the tensile strength being increased 150 per cent. by eight hours of continued fusion. A clause should be inserted in a specification for cast-iron pipes, providing that a test-bar, cast from time to time, shall, when placed edgeways on bearings 36 inches apart, support a certain weight.

Test-bars 1 inch × 2 inches in section and 3 foot 6 inches long should be capable of supporting a weight of 30 cwts. gradually applied at the middle of the bar.

Pipes should be cast socket downwards in dry sand-moulds, and run, as quickly and equally as possible, in one operation, so as to avoid a "cold shut." Pipes 4 inches and upwards in diameter should be cast vertically; under 4 inch, at an angle of 45°. The strength at the spigot-end is increased by casting a head or additional 6 inches or more beyond the finished length of the pipe, which is afterwards cut off in the lathe. The head has the effect of compressing the metal, and permits the ash and bubbles to rise into and be removed with it. The pipes should be straight, cylindrical, and free from chaplets, core nails, and other imperfections, and the metal should be of uniform thickness throughout. The consecutive number, year, and maker's name should be cast on each pipe, the numbers on rejected pipes being disfigured by a chisel-cut, and no number of a rejected pipe must be replaced.

CHAPTER XVIII.

PIPES—*continued.*

THE pipes, after being cleaned, are struck all round with a light hammer, and, if sound, are placed in the testing machine (Fig. 48) and tested by oil or water; the former is perhaps better for the iron-work, but is more costly, and the benefits derived therefrom small. Gaskets or steel rings wrapped with yarn are hung at each end of the pipe, to form a joint with the iron plates, one of which (*a*) is fixed, and the other (*b*) movable, the latter being driven forward by a screw and

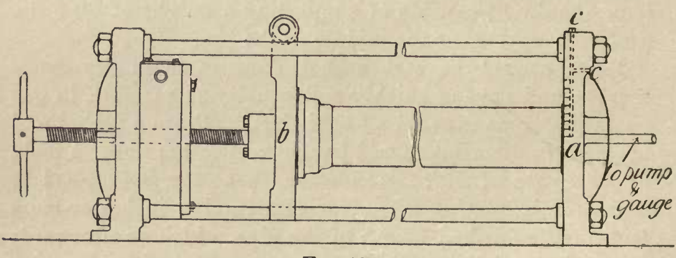


FIG. 48.

gearing worked by hand. The screw-plate has an air-pipe (*c*) cast in it, through which the air escapes, as the water, flowing in, fills the pipe under test. When the water flows full-bore through the air-pipe, showing that the air has escaped, the valve is closed and the screw-plate tightened up, the pump having been started just before. The pressure-gauge, which should be placed in a conspicuous position, records the rise of pressure. Attention must be given during

the whole of the testing operation to the behaviour of the pipe. When the testing limit is reached, a valve between the pump and the testing-machine is closed, shutting off the connection with the pump and allowing the pipe to remain under the specified pressure while it is examined and struck with a hammer. During this period the gauge should remain stationary, unless there is a loss from leakage, which must at once be stopped and the test re-started. After being tested for pressure, the pipe is tested for thickness and uniformity of metal by means of calipers and a disc (Fig. 49). The examination being satisfactory, the pipe is conveyed to a heating-stove and raised to a temperature of 400° Fahr.,

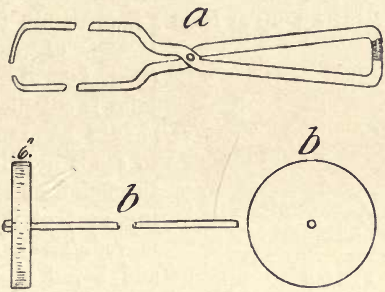


Fig. 49.

previous to dipping it in what is termed Dr. Angus Smith's composition, consisting of pitch, asphalt, resin, and linseed oil at a temperature of 300° Fahr. The pipe is then ready for delivery on the site of the works. The pipes are lowered into the trench prepared for them, either by hand by means of rope, or by a block-and-tackle arrangement attached to tripod legs. The trench is sufficiently enlarged at the junctions of the pipes, so as to admit of the jointing material being properly filled, caulked, and examined. Each pipe is struck with a hammer for soundness, and the spigot end carefully driven up into the socket of the preceding pipe, after which it is ranged in line and set at the required level, attention being paid to the even thickness of the joint. The

lead joint is made by driving a gasket of strip lead or a few coils of yarn into the space between the spigot and the socket by means of a yarning-iron (Fig. 50, *a*). The former method is coming into general use, and is preferable on sanitary grounds, as the yarn becomes a nest for bacteria. The gasket having been driven tightly up to the back of the socket, the joint is ready for the clay luting, which is placed around the lead space at the face of the socket, with a lip at the top to receive the molten lead. Care must be taken to remove the dross before running the molten lead, which must in all cases be done in one operation, so as to ensure a solid joint throughout. The lead having become solidified, the clay luting is removed, the surplus lead at the lip cut off, and the joint set up at least $\frac{1}{8}$ inch within the socket by means of caulking-tools (Fig. 50, *b*). After each joint is completed the pipe should be examined inside to see if any lead has run through from careless yarning, so that it may be removed. The joints of turned and bored pipes are made by painting the machined portion with thin red lead or liquid Portland Cement. The spigot is then placed within the socket and driven up with a wooden maul. The labour entailed in laying this class of pipes is small, and the general experience where they have been adopted is that they are quite equal to lead joints except for turning curves, where the lead joint may be utilized as well as for expansion purposes already referred to. Wrought-iron or steel pipes are largely used in the smaller sizes for connecting services in the place of lead pipes, where the water is of such a nature as to attack the lead and produce lead-poisoning. The pipes consist of strips of metal either welded or solid drawn, with screwed socket-joints; they are usually galvanized, and can be manufactured to suit any pressure required. Wrought-iron tubes are made in lengths

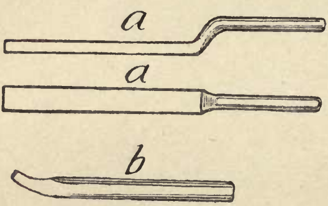


FIG. 50.

usually not exceeding 14 feet, but can be obtained up to 20 feet in length if necessary. They are made in three qualities —gas, water, and steam—the steam-tubes being two gauges, and the water-tubes one gauge thicker than the gas-tubes.

The following table give the results of Messrs. J. Russel's experiments with wrought-iron solid-drawn tubes, according to Mr. D. K. Clark.

External diameter.	Thickness.		Internal diameter.	Bursting pressure.		Collapsing pressure.		Difference between bursting and collapsing pressure.
				Per sq. in. of surface.	Per sq. in. of section of metal.	Per sq. in. of section.	Per sq. in. of section of metal.	
Inches.	B.W.G.	Inches.	Inches.	lbs.	Tons.	lbs.	Tons.	Tons.
$3\frac{1}{4}$	10	·134	2·982	4800	23·84	3300	17·86	5·98
$3\frac{1}{8}$	10	·134	2·857	4500	21·42	3150	16·40	5·02
3	11	·120	2·760	4500	23·10	3500	19·53	3·57
$2\frac{3}{4}$	11	·120	2·510	5200	24·28	3500	17·89	6·39
$2\frac{1}{2}$	11	·120	2·260	5000	21·02	3600	16·74	4·28
$2\frac{1}{4}$	11	·120	2·010	5900	22·06	4500	18·82	3·24
2	12	·109	1·782	5900	21·53	4900	20·07	1·46
$1\frac{3}{4}$	12	·109	1·532	5600	17·57	4000	14·33	3·24

The greater tensile strength of wrought-iron and steel, and their lightness compared with cast-iron, give them great advantages over the last metal in such cases where weight and strength are the main objects, although for cheapness and convenience in casting, as well as the greater thickness for corrosion, it is doubtful whether wrought-iron or steel will replace cast-iron in the manufacture of pipes. The action of the Bradford Corporation, in adopting them in their new works, may lead to their more general use for large mains in somewhat inaccessible districts, where the question of weight is a serious one.

Lead pipes are of almost universal application for service connections and interior fittings, on account of the facility with which they can be bent to suit the irregularities of structure, and it is a matter of importance that they should be of good quality and of sufficient strength for the purpose. The following table gives the sizes of pipe usually specified for service connections:—

½ inch	diameter	6 lbs.	per yard.
¾ inch	„	9 lbs.	„
1 inch	„	12 lbs.	„
1¼ inch	„	16 lbs.	„

Any of these pipes would stand a pressure of 500 feet head of water. Several methods have been proposed for preventing the solvent action of some waters upon the lead, one of which is to line the interior of the pipe with block tin; but none of the many proposals have been largely adopted.

Clay pipes are frequently used for conveying water in collecting-drains and other situations where there is no head of pressure on the pipes. The joints are either left dry or filled with Portland cement, as the circumstances require.

The following table of the dimensions of clay pipes was adopted by Mr. Baldwin Latham for the Bideford Waterworks:—

Internal diameter.	Stoneware.		Fireclay.		Other clays. Thickness.	All pipes, depth of socket.
	Thickness.	Length in work.	Thickness.	Length in work.		
Inches.	Inches.	Feet.	Inches.	Feet.	Inches.	Inches.
2	—	—	—	—	$\frac{5}{16}$	—
3	⅜	2	⅜	2	⅜	1½
4	½	2	½	2	½	1½
6	⅝	2	¾	2	¾	1¾
9	¾	2	⅘	2	⅞	2
10	⅞	2	1	2	—	—
12	1¾	2	$1\frac{1}{10}$	2	1	2
15	1⅛	2	1¼	2 to 3	1¼	2¼
18	1¼	2 to 3	1½	2 to 3	2½	2½

When extensive works are being carried out it is customary to appoint an inspector to be present during the entire operations of casting and testing at the foundry. This entails a considerable expense which cannot be borne by a small undertaking. As the pipes are liable to suffer from shocks and concussions from rough handling and other causes in transit from the foundry to the site of operations, as well as from injuries in the course of jointing and lowering into the trenches, such inspection alone is not always satisfactory. In support of this view the experience recorded in connection with the waterworks construction at Market Harborough by Mr. H. G. Coates, A.M.I.C.E., may be instanced. The pipes were cast and tested at the foundry under the supervision of an inspector, the tests being conducted in accordance with the following schedule :—

Diameter of pipe.	Thickness of pipe.	Proof pressure equal to a column of water.	Or lbs. per sq. in.	Maximum pressure in feet to which pipe will be subjected in work.
Inches.	Inches.	Feet.		
10	$\frac{1}{2}$	450	195	205
8	$\frac{1}{2}$	450	195	205
7	$\frac{7}{16}$	300	130	20
6	$\frac{7}{16}$	450	195	205
4	$\frac{3}{8}$	500	217	215
2	$\frac{5}{16}$	500	217	210

The pipes being struck with a hammer in all their parts whilst under pressure. Test-bars of the metal actually used were also carefully proved.

The whole of the system, comprising $8\frac{1}{4}$ miles of 10-inch, 65 yards of 8-inch, 2 miles 1410 yards of 6-inch, 5 miles 850 yards of 4-inch, and 1380 yards of 2-inch pipes, were

subsequently tested in sections in the trenches by hydrostatic pressure to 50 lbs. per square inch above the working pressure. The following is a list of the rejected pipes resulting from this second test—

460	10-inch	pipes
89	6-inch	„
97	4-inch	„
10	2-inch	„

weighing about 141½ tons, or over 8 per cent. of the weight delivered.

To enable the process of testing in the trenches to be conducted economically, the pipes should be laid from the reservoir towards the site of distribution, so that the water may follow the work, and the cost saved of filling the sections to be tested by water-carts.

The method of testing is as follows. The terminal pipe is closed by means of a blank socket, drilled and tapped to receive the connection-pipe from the pressure-pump. The connecting-pipe may consist either of a short length of strong hose—which is undoubtedly the most convenient—or of wrought-iron tube with proper bends. In either case the connection with the pump should be made by means of a screw-union, so that the machine can be easily disconnected. The pump usually consists of a small pressure-pump, similar to that used for testing boilers, mounted over a tank or reservoir, which is frequently placed on wheels. A water pressure-gauge, showing the pressure in feet of water and in lbs. per square inch, is attached where it can be easily seen, also a safety-valve, and valve for lowering the pressure.

The section of pipe to be tested is then slowly charged with water by opening the sluice-valves between it and the reservoir, the air in the pipes being got rid of by means of the air-valves and ball-hydrants (if any) on the section. It is well to open the valve for lowering the pressure, above referred to, and to allow the escaping water to carry the air with it. The importance of getting rid of as much air as possible is great, both on account of

the time and labour saved in getting up the pressure, as well as the danger from flying pieces of pipe, etc., were a burst to take place. In a small waterworks now being carried out the two following tests were made :—

1. Length of section, 420 yards; diameter of pipes, 3 inches; pressure attained, 230 lbs. per square inch. Time, 10 hours.

2. Length of section, 250 yards; diameter of pipes, 2 inches; pressure attained, 230 lbs. per square inch. Time, 3 minutes.

In the former case the line of pipes was undulating, and the air lodged in the high points. In the latter case the pipes were laid at a uniform slope. Having dislodged as much air as possible, the valve for lowering the pressure and the nearest sluice-valve should be tightly closed and pumping commenced. The pump-tank is kept constantly filled by means of a water-cart or by buckets, the quantity of water required depending upon the amount of air in the pipes and the number and extent of leakages.

The line of pipes should be carefully examined while the pressure is rising, and pegs driven or marks made at any sign of failure. When the pressure has risen, as shown by the gauge, to the proof point, which should be at least double the working head, it should be kept there while the pipes are submitted to a close scrutiny. It must be noted if the needle remains steady when pumping ceases, or falls more or less rapidly. The behaviour of the needle under these circumstances greatly depends upon whether the instrument is situated at the highest or lowest level of the section under test. In the former case a slight leak will cause the needle to fall rapidly; in the latter the needle will be scarcely affected.

No part of the trench must of course have been filled in until the testing has been satisfactorily completed, and any water in the trenches must, if possible, be removed, otherwise the examination is bound to be imperfect.

The most familiar failures are split or cracked pipes, honeycombed-sockets, pin-holes, blown core-nails, and

leaking joints. Each point of failure must be carefully recorded by means of a peg or intelligible mark. The pressure is then lowered, defects made good, and the section re-tested.

Pin-holes in otherwise sound pipes may be drilled, tapped, and plugged with brass or gun-metal plugs, but only with the special permission of the engineer in each case. Weeping joints may frequently be remedied by the application of the caulking-tool. Honeycombed or perforated sockets, or split pipes, must be cut out, and the line of pipe made good by means of a short piece cut to the requisite length, and a thimble or sleeve.

Corrosion or rusting of iron pipes, both externally and internally, is an element not to be lost sight of by the engineer. Externally it is caused either by the oxygen in the water attacking them where the pipes are laid in damp ground, or by the presence of corrosive substances in the soil, which occasionally occurs in the neighbourhood of chemical works, etc. The former, in the case of cast-iron pipes, may be neglected if they are properly protected by coating with Dr. Angus Smith's solution, on account of the comparatively great thickness of the shell; the latter must be prevented, where necessary, by embedding the pipes in concrete. Internally, corrosion is caused by the oxygen in the water attacking the metal, and is usually more serious with soft than with hard water. The coating of the interior of the pipes with the protecting solution must be carefully attended to, and made a special point in their inspection. Even with the most careful coating corrosion is almost certain to occur, but the process will greatly delay it; minute points are left unprotected, and corrosion will take place, gradually scaling off the intervening varnish where these points are close together. The danger of weakening the pipes is small, for the reason above stated; but the real trouble lies in the contraction of the bore of the pipes caused by the nodules of rust (the rust does not form in even layers), which diminishes their discharging capacity and reduces the working head. Mr. Thomas Box ("Practical Hydraulics")

records a case at Torquay where a main, about 14 miles long, composed of 14,267 yards of 10-inch, 10,085 yards of 9-inch, and 170 yards of 8-inch pipe delivered only 317 gallons per minute, with 465 feet head, or only 50 per cent. of the theoretical discharge. The pipes were subjected to repeated scraping by means of scrapers worked through their entire length, the result of which was that the experimental discharge was brought up to the theoretical.

On account of corrosion, wrought-iron tubes for conveying water should always be galvanized. In designing systems of pipes it is always advisable to increase the calculated diameter so as to allow for corrosion.

The following memoranda will be useful to the student when calculating the weight of pipes:—

Wrought-iron, 1 cubic inch, 0·278 lbs.; 1 cubic foot, 480 lbs.

Cast-iron, 1 cubic inch, 0·260 lbs.; 1 cubic foot, 450 lbs.

Steel, 1 cubic inch, 0·283 lbs.; 1 cubic foot, 489·6 lbs.

Lead, 1 cubic inch, 0·412 lbs.; 1 cubic foot, 712 lbs.

Gun-metal, 1 cubic inch, 0·304 lbs.; 1 cubic foot, 524 lbs.

CHAPTER XIX.

FIRE-SERVICE, VALVES, AND METERS.

THE details necessary for the provision of an efficient fire-service too often receive but scanty attention in waterworks construction, especially in rural districts. The advantages of having a powerful stream of water, easily put into requisition, and capable of playing upon any portion of a building in a state of conflagration, are too great to need impressing upon the student. It is necessary, however, to point out that these facilities can frequently be attained at very little extra cost, if the necessary arrangements are included in the original design of the waterworks, whilst the cost of their subsequent provision may be prohibitive. The principal points to be kept in view in making provision for fire-service are :—

1. That there shall be a surplus storage of water for fire extinction over and above that required for general purposes, and always available.

2. Such storage to be at a sufficient elevation to allow of the water being forced above the tops of the highest buildings in the district.

3. The mains and distributing pipes to be of such dimensions as to allow of the water for fire extinction purposes being conveyed through them when the demand for water for other purposes is at its greatest.

These requirements cannot always be secured in their entirety, but they indicate the lines which must be kept in view. The surplus storage is usually included in the

capacity of the service-reservoir, and the amount to be allowed for must depend upon the special requirements of the district under consideration, as well as upon the means at the disposal of the engineer.

Assume, for the sake of example, that on the grounds of probability and expediency, only one fire at the same time in the district is to be provided for, that the probable time occupied in extinguishing the fire will be three hours, and that one jet, 50 feet high, will be required. Theoretically, the height of the water issuing vertically from a jet, should be equal to the head upon the jet, but the resistance of the air causes a considerable reduction. Experiments show that the difference between the theoretical height and the actual height attained by a jet of water varies approximately, directly as the square of the theoretical height, and inversely as the diameter of the jet.

Mr. Box ("Practical Hydraulics") gives the following formula:—

$$h' = \frac{H^2}{d} \times \cdot 0125$$

Where $H =$ the head on the jet in feet.

" $h' =$ the difference between the height of the head and the height of the jet.

" $d =$ diameter of the jet in $\frac{1}{8}$ths of an inch.

It is evident from the above relations that in order to obtain the best results from the available head, a jet of special diameter corresponding to that particular head must be used. Assuming an available head of 70 feet at the point under consideration, then—

$$h' = 70 - 50$$

$$d = \frac{H^2 \times \cdot 0125}{20} = 3$$

or the proper diameter of jet to be used, under the circumstances, is $\frac{3}{8}$ths of an inch. The quantity of water discharged by a jet with a given head depends upon the form of the jet (see Chap. X., gauging by means of an orifice), the best form being that which approaches most nearly to the *vena contracta* (Fig. 51). The discharge through this form of

jet may be taken as ·943 of the theoretical discharge due to the head.

Applying this coefficient to the formula—

$$Q = 8{\cdot}025\, c\, a \sqrt{h}$$

$$Q = 8{\cdot}025 \times {\cdot}943 \times [(\tfrac{3}{8})^2 \div 144 \times {\cdot}7854] \times \sqrt{70}$$

$= {\cdot}04856$ cubic feet per second.

$= 18{\cdot}21$ gallons per minute.

If the jet is required to play for 3 hours, then the quantity of water discharged will be $18{\cdot}21 \times 60 \times 3 = 3277{\cdot}8$ gallons. It would, therefore, be necessary to provide surplus storage capacity in the service-reservoir for, say, 4000

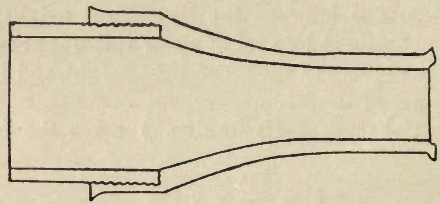


FIG. 51.

gallons; and the diameter of the mains and distributing pipes must be chosen so as to allow of an extra quantity, equal to 18·21 gallons per minute, being conveyed through them when the demand for water for other purposes is at its greatest.

In order to render a fire-service efficient, it is necessary that a sufficient number of hydrants should be provided upon the system, the situations being selected with great care, so that each may yield the maximum of efficiency. They should be easily accessible, capable of rapid manipulation, not difficult to find in the dark, and so constructed as not to be affected by frost.

In designing a waterworks system, the available head at any point is arrived at by deducting the loss of head due to friction in the pipes from the statical head at that point (Chap. XI.). It must be remembered that these results will only hold good provided the system is watertight, allowing

practically no waste. Sir Frederick Bramwell, speaking of the evils of waste, at a recent meeting of the Institution of Civil Engineers, expounded this point very clearly.

"Another point was the diminution of the pressure in the pipes. It was impossible to obtain an extra amount of water through a given-sized main, except by having a greater differential pressure between the entering end and the delivery end of the main. The entering end of the main was fixed by a reservoir or a stand-pipe level, or whatever it might be, and the consequence was that the increase in the differential pressure must be obtained by diminishing the pressure at the delivery end. What was the result? Any hope of using the water for hydrant purposes, for extinguishing fires, was gone: there was no pressure for that."

The two principal types of hydrants or fire-cocks are the sluice-valve and the ball-hydrant. There are innumerable forms in the market, but they are all modifications or combinations of these two types. The sluice-valve hydrant consists, as its name implies, of a sluice-valve connected with the main, with a bend attached to its outlet fitted at its upper end to receive a stand-pipe to which the hose is fixed. The stand-pipe is either fitted to the hydrant by a screw or bayonet-joint. The stand-pipe is sometimes a fixed pillar, which has the advantage of easier access at times of fire. The sluice-valve is the best form of hydrant, but entails a heavier first expense than the ball-hydrant. A frost-cock, which may be automatic, must be attached on the outlet side of the sluice-valves, for the purpose of removing the water which would otherwise remain in the bend (or pillar) after use.

The ball-hydrant, patented by Messrs. Bateman and Moore, consists of a vulcanite ball contained in a valve-box; the outlet to the box, which is vertically above the ball, and is fitted with a leather or indiarubber washer, being kept constantly closed while the water in the main is under pressure, by the ball, which is lighter than the water, being forced up against it. The stand-pipe is attached to the

hydrant by means of a bayonet-joint; and the valve is opened by depressing the ball by means of a spindle passing down through the stand-pipe and worked by a crutch-handle. Ball-hydrants are economical, and work exceedingly well with moderate heads. With low heads they are apt to leak, and with high heads the ball is liable to be forced out of shape, causing leakage when it takes a new bearing upon its seat. Another objection is caused by the suction into the main through the ball-hydrant, when the former is being emptied of any liquid matter, frequently of a filthy nature, which may be at the time in the hydrant-chamber. Ball-hydrants also act as air-valves, but with very doubtful advantage, on account of the large orifices, which allow the air to escape so rapidly, while the main is being charged, as to endanger the pipes by shocks.

Air-valves are used for the purpose of getting rid of the air which constantly accumulates at the highest points of undulations in the line of pipe, especially where such points are situated above the hydraulic mean gradient (see Chap. XI.). They are either automatic, in which case they are identical with the ball-hydrant, except that the aperture which serves for the escape of the air is much smaller ($\frac{1}{8}$ to $\frac{3}{8}$ inch in diameter); or they consist of small stop-cocks, opened and closed by hand.

Sluice-valves vary little in form, and usually consist of a cast-iron body containing a movable diaphragm which slides vertically between grooves. The sliding faces, both of the body and of the movable valve, should be made of gun-metal, as well as the screw which actuates the valve and the stuffing-box gland through which the screw works. It is best to obtain them with spigot and socket ends attached by means of bolts and nuts, so that they can be removed if necessary without cutting the pipes. Sluice-valves should be fixed at all branches in a waterworks system; and the mains and branches should be divided up into easily worked sections by means of sluice-valves, so that each section may be isolated from the rest with a minimum of inconvenience to the consumers generally. Sluice-valves should be

plentiful on all waterworks systems, and it is false economy to attempt to make a saving by reducing their number.

Water-meters are inserted in a line of pipe for the purpose of measuring and registering the flow of water passing through them. There are two types—the positive and the inferential. The positive meter measures the flow of water by causing it to alternately fill and empty a vessel of known capacity, the number of times that this process takes place being recorded by means of a clockwork mechanism. The positive meter is sub-divided into high and low-pressure meters—the Duncan, Kennedy, Frost, Schönheyder, Frager, and Kent meters representing the former; the Parkinson and Tylor representing the latter class. The inferential meter consists of a chamber through which the water flows, containing a wheel with vanes or discs attached. The water in passing impinges upon the vanes and causes the wheel to revolve, the revolutions being recorded as in the positive meter. The Siemens, Tylor, and Sporton meters are instances of this type. The mechanism of the positive meter is similar to that of the cylinder and slide-valve of a high-pressure steam-engine, while that of the inferential meter may be compared to a water-wheel or turbine. Messrs. Turner and Brightmore ("The Principles of Waterworks Engineering") give the following essentials as characteristic of a perfect water-meter:—

1. Accurate registration of the quantity of water passing through it, whether great or small.

2. Ability to perform its work without causing a material loss of head in the supply-pipe.

3. Cheapness and simplicity.

4. Ease of attachment and repairs.

5. Freedom from excessive wear of the working parts.

Section 58 of the Public Health Act, 1875, empowers a Local Authority "to agree with any person to supply water by measure, and as to the payment to be made in the form of rent or otherwise for every meter provided by them." The question as to whether the supply of water for domestic use should be charged for by measure has been largely

discussed. There is a strong feeling against this method on sanitary grounds, so far as it applies to houses of low rental; the objection raised against it being that water would be economized at the expense of cleanliness and health, in the very situations where these are of the greatest importance to the general community. Where the water is supplied for trade or manufacturing purposes the case is different, and, where it can be arranged, the sale should be by meter. This question is of the most importance where the water has to be pumped.

Meters have not been largely introduced into rural districts, although they can be applied with great benefit to farm—especially dairy farm—supplies. In a dairy farm where the milk is refrigerated, the consumption of water for that purpose alone is frequently 1000 gallons a day.

As the size of the pipe for conveying a supply of water to any premises frequently depends upon other considerations than its capacity for delivering that supply, it must not be taken as the gauge of the meter to be inserted on its line. The following table, which refers to Sieman's inferential meter, will be found useful in deciding upon the size of meter applicable in any particular case :—

No.	Inch.	Delivery in gallons per hour.	
		50 feet head.	150 feet head.
1	3/8	150	250
2	1/2	300	500
3	3/4	600	1,000
4	1	1,500	2,500
5	1 1/4	2,200	3,800
6	1 1/2	3,000	5,000
7	2	4,000	7,000
7 1/2	2 1/2	6,000	10,000
8	3	8,300	14,000
9	4	13,400	23,000
10	5	18,500	32,000
11	6	27,000	46,000
12	8	45,000	77,000
13	10	70,000	120,000
14	12	90,000	154,000

It is always better to allow a safe margin in deciding upon the size of a meter. Where the water is expensive, either on account of pumping or where it is purchased by measure by the undertakers in the first instance, it will be found a wise precaution to insert meters on all large connections as a check upon waste and undue consumption, where the consumer is not to be charged by measure.

CHAPTER XX.

HOUSE CONNECTIONS AND FITTINGS.

In order to secure satisfactory results in a waterworks undertaking, it is necessary to keep a strict control over the connections that are made by consumers with the undertakers' pipes for the purpose of obtaining a supply of water for domestic or other purposes. Waste is the *bête noire* of the waterworks engineer, and experience has shown that its favourite lair is to be found in the communication-pipes, taps, cisterns, and overflow-pipes connected with house and trade supplies.

As indicated in Chapter XIX., the difficulty where it applies to trade connections can be satisfactorily met by the insertion of water-meters, and by charging for the actual quantity of water delivered to the premises in question. When persons have to pay for water by meter, whether used or wasted, it becomes to their interest to detect the sources of waste; on the other hand, it is against the immediate interest of owners of house property to detect leakages or faulty fittings, which they would have to repair or replace at their own cost, without obtaining thereby any reduction in their water-rates.

To enable a Local Authority, *inter alia*, to suppress waste, the Waterworks Clauses Act, 1863, and certain provisions of the Waterworks Clauses Act, 1847, were incorporated with the Public Health Act, 1875. These enactments afford very meagre powers to Local Authorities, so far as giving them any control over domestic services is concerned. It is customary for the undertakers, when seeking for a

special Act, to apply for extended powers. These powers, when obtained, are set forth in the form of "water regulations," to be considered in the next chapter. It may here be observed, parenthetically, that no provision is made in the Public Health Acts, empowering Local Authorities to make water regulations.

The sections of the Waterworks Clauses Acts (1863, and part of 1847) directly or indirectly enabling Local Authorities to place some check upon the waste of water in domestic services are the following:—

The Waterworks Clauses Act, 1847.

Sec. 28 empowers the undertakers to break up streets, etc., for the purpose of supplying water to the inhabitants of the district.

Sec. 44 requires the undertakers to lay down communication-pipes and other necessary works to any dwelling-house (under £10 rental) situated in any street where they have laid pipes (1) either at the request of the owner, or (2) at the request of the occupier, and upon payment or tender of the proportion of water-rate in respect of such house by this or the special Act, made payable in advance. Such reasonable annual rent for such pipes to be charged as may be agreed upon, or as may be settled by two justices.

Under these circumstances, the undertakers are enabled to employ efficient workmen and fix proper fittings.

Sec. 48 empowers the owner or occupier, having paid or tendered to the undertakers the portion of the water-rate as indicated in sec. 44, to open the ground and lay leaden or other communication-pipes between his premises and the undertakers' pipes, provided—

1. That he has obtained the consent of the owner and occupier of the intervening ground;

2. That the pipes are of a strength and material to be approved by the undertakers;

3. That fourteen days' notice has been given to the undertakers.

Sec. 49 requires the owner or occupier to give two days' notice of day and hour when communication is intended to be made. Communication to be made under superintendence, and according to the directions of the undertakers' surveyor, or other officer appointed, unless such surveyor or other officer fail to attend at the time mentioned in the notice.

Sec. 50 enacts that the bore of such communication-pipe shall not exceed the prescribed limits; or, if no limit has been prescribed, $\frac{1}{2}$ inch, except with the consent of the undertakers.

Sec. 52 gives owner or occupier the same privileges as the undertakers as to breaking up roads.

It will be evident to the student, after a perusal of these sections, that the undertakers' control over a domestic supply is limited to the communication-pipe, and does not extend to the fittings.

Sec. 54 applies only to intermittent systems, and enables the undertakers to require the consumer to provide a proper cistern, ball, and stop-cock, and to keep them in repair. It has been held that the undertakers cannot enforce the provision of a valve instead of a plug-cock.

Sec. 56 (in continuation of sec. 54) empowers the undertakers to repair such cistern, aud to recover the expense.

Sec. 57 gives power of entry to the surveyor or other person acting under the authority of the undertakers, for the purpose of detecting waste or misuse of water.

Secs. 58 and 59 impose penalties on misappropriation of the water; and

Sec. 60 imposes a penalty upon any person who shall wilfully or carelessly break, injure, or open any lock, cock, valve, etc., the property of the undertakers.

The Waterworks Clauses Act, 1863.

Sec. 12. A supply of water for domestic purposes shall not include a supply of water for cattle, or for horses, or for washing carriages where such horses or carriages are kept

for sale or hire by a common carrier, or a supply for any trade, manufacture, or business, or for watering gardens, or for fountains, or for any ornamental purpose.

Water used for watering a horse and washing a carriage has, however, been held to be used for "domestic purposes" within the meaning of an enactment similar to the above section. Water used for a pleasure garden was held to be for a "domestic purpose."

Sec. 14 gives the undertakers power to let meters, cisterns, pipes, etc., on hire.

Sec. 16 empowers the undertakers to cut off the supply, if any of the provisions of the Act are contravened.

Sec. 17 imposes a penalty upon the consumer for waste of water through non-repair of pipes, taps, etc.

Sec. 18 imposes penalty upon misappropriation of the water.

Sec. 19 imposes penalty upon any alteration to service as follows: "It shall not be lawful for the owner or occupier of any premises supplied with water by the undertakers, or any other person, to affix, or cause or permit to be affixed, any pipe or apparatus to a pipe belonging to the undertakers, or to a communication or service-pipe belonging to or used by such owner, occupier, consumer, or other person, or to make any alteration in any such communication or service-pipe, or in any apparatus connected therewith, without the consent, in every such case, of the undertakers."

Sec. 20 imposes a penalty upon any person using the undertakers' water without agreement.

The powers possessed by a Local Authority for the prevention or suppression of waste in domestic connections may be summarized as follows:—

1. Where the dwelling-house is under £10 rental, and a request has been made by the owner or occupier for a supply of water, the Local Authority have control over workmanship, materials, and choice of fittings.

2. Where the owner or occupier makes his own connection, the Local Authority may superintend the communication or junction with their pipes; in such case the communication

to be made under their direction. The communication-pipes to be of a strength and material to be approved by the undertakers, the bore not to exceed the prescribed limit, or, if no limit, ½-inch.

3. The Local Authority has power to enter any house supplied by them with water, between the hours of 9 a.m. and 4 p.m., for the purpose of detecting waste or misuse of water.

4. Where the supply is intermittent, the Local Authority may require the provision of a proper cistern to hold the water so supplied, with a ball and stop-cock in the pipe bringing the water from the works of the Local Authority to such cistern; also to require that such cistern, etc., shall be kept in proper repair so as to prevent waste; also to, themselves, repair such cistern, etc., and recover the expense.

5. Power to impose a penalty for waste of water through non-repair of pipes, etc.

6. Power to impose a penalty for any alteration to service without the consent, in each case, of the Local Authority.

7. Power to cut off the water if any of the provisions of the Act are contravened.

These powers are utterly inadequate to the proper control over a waterworks, and as it is unusual for a Local Authority (especially a Rural Authority) to go to the expense of a special Act, so-called "Water Regulations," which, however, cannot be legally enforced, are not infrequently formally passed and published by the Local Authority, and generally attain the required result.

To meet the difficulty of not having sufficient control over domestic fittings, a system of testing and stamping was introduced in 1883 by Mr. Ernest Collins, M.I.C.E., the engineer to the New River Company, London. Mr. Collins says, "The system then introduced has developed extensively; and there has been a material improvement in the quality of the fittings. Manufacturers who were at first antagonistic to the arrangements, have become strong supporters of the system, insomuch that the

use of untested and unstamped fittings is, in the district of the company mentioned, almost the exception; and where such fittings are used, they are invariably of the same strength and proportions, and in accordance with the regulations adopted by the company."

The same system had been previously (1873) introduced at Liverpool, with the same object, by the engineer, Mr. G. F. Deacon, M.I.C.E. Of this system, Mr. Deacon says, "Very little difficulty was experienced. Naturally the plumbers at first rebelled, but in a short time they were glad to have their names put on the backs of the waste-water notices."

Where new connections are to be made with the undertakers' pipes for domestic or other supply, it is now almost universally the practice for the undertakers to tap the main themselves, and lay, at their own expense, the communication-pipe to the fence or frontage wall (if there be one) forming the boundary of the street or highway in which their main is situated. At the termination of the pipe a stop-cock is fixed, to which the consumer attaches his own work. There has been much discussion as to the advisability or otherwise of the practice of fixing outside stop-cocks, but in a rural system, at any rate, there can be little doubt as to its usefulness. The principal advantages are (1) Facility with which water can be turned off by the undertakers in the case of waste, or when premises are unoccupied; (2) Facility afforded for detecting waste in mains or connections. This stop-cock, and all other cocks or taps used throughout the premises, should be of the screw-down type. The following are the requirements of the New River Company: "All taps must be fitted with loose valves; and such valves must be lifted by the spindle, and must not be dependent upon the pressure of water for opening. They must be fitted with washers of oil-dressed leather, and for hot water with vegetable fibre of the best quality. Stop-taps must have set screws to secure flanges. The word 'inlet' must be distinctly marked on the inlet side of the tap. They must be made with screwed ends and unions.

Spindles must, in all cases, be of gun-metal. All other parts may be of brass, of good suitable quality. Screw-down fittings must have four threads of spindle in the cover when closed" (Fig. 52).

It is essential that all overflow pipes from cisterns, baths, etc., be constructed as warning-pipes, the mouth of such warning-pipe to be conspicuously placed so that any waste cannot fail to draw immediate attention. On no account must any overflow be allowed to escape directly into any waste-pipe or drain. An important point is to see that all

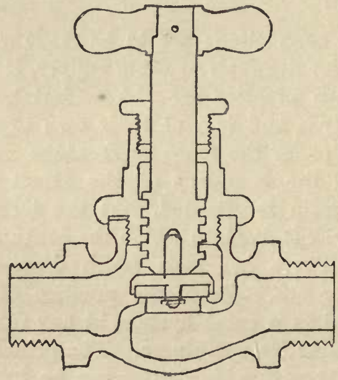


FIG. 52.

pipes are properly protected from the action of frost. This is rarely attended to, and consequently the waste during the winter months from burst pipes and taps, as well as the unnecessary expenditure of water caused by leaving taps running to prevent what should have been rendered impossible, is often enormous.

Instead of making a separate connection for each house, where the houses are close together and are of small rental, it is usually the custom for the undertakers to erect stand-posts or pillars from which the inhabitants of the houses can obtain their supply.

To facilitate this practice sec. 9 of the Public Health (Water) Act, 1878, enacts as follows:—

"Where a Rural Sanitary Authority have provided a stand-pipe for the supply of water to any portion of their district, they may recover water-rates or water-rents from the owner or occupier of every dwelling-house within 200

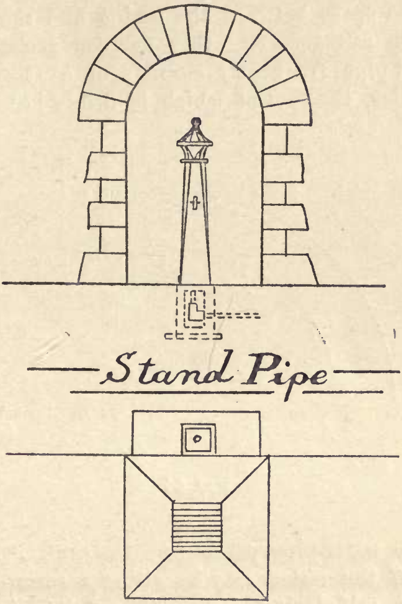


FIG. 53.

feet of any such stand-pipe, in the same manner in all respects as if the supply had been given on the premises.

"Provided that if any such dwelling-house has, within a reasonable distance, and from other sources, a supply of wholesome water sufficient for the consumption and use of the inmates of the house, no water-rate or water-rent shall be recoverable from the owner or occupier of the house unless

and until the water supplied by means of such stand-pipes is used by the inmates of the house."

Stand-pipes consist of a ½-inch or ¾-inch pipe running up a post or convenient wall, terminating in a tap fixed at such a height as will easily allow of a pail or bucket being placed under it when being filled (Fig. 53). The pipe is protected from the frost by means of a wooden or iron casing—the space between the casing and the pipe being filled with saw-dust or other non-conducting substance. The stand-pipe frequently consists of a strong cast-iron hollow pillar, the foot of which is firmly bedded into the

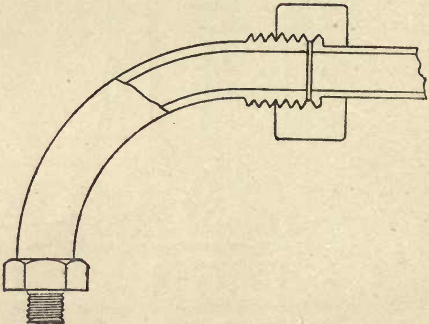


FIG. 54.

ground, the water-pipe passing up the centre. The tap for drawing off the water may be either a screw-down valve-cock or a self-closing cock. The latter is sometimes unsatisfactory with very high pressures. A stop-cock should always be inserted between the main and the stand-pipe to cut off the supply when the latter is being repaired. A grating should be placed under the tap, with a drain to carry away the waste water. A small tap is frequently placed at the foot of the stand-pipe to act as a frost-cock; the stop-cock is closed and the water in the stand-pipe emptied by allowing the water to flow away into the drain by means of the frost-cock.

Small connections are generally made with the mains by means of ferrules, which consist of small brass elbows, one end of which is screwed (Fig. 54) into a hole drilled and tapped into the top of the main; the other end has a union for attaching to the lead or wrought-iron service-pipe.

CHAPTER XXI.

WATERWORKS REGULATIONS.

In accordance with the provisions of the Metropolis Water Act, 1871, a code of regulations was compiled by the Metropolitan Waterworks Companies and submitted to the Board of Trade.

These suggested regulations were subjected to an exhaustive inquiry, and, as finally settled, have been circulated by the Local Government Board for the information of Local Authorities who have obtained the necessary powers, and are preparing to submit regulations for confirmation. As it is customary for Local Authorities supplying water, and acting only under the provisions of the Public Health Acts, to issue a code of Waterworks Regulations, trusting to their moral suasion and to the popular ignorance of the law for their efficacy (a trust by no means unfounded), a brief commentary upon the regulations under the Metropolis Water Act, 1871, is given here. These regulations are by no means perfect, or are they fitted for all cases. In adapting them for use in rural districts, latitude must be given to many of the provisions, care being taken that the main principles involved are not lost sight of.

No. 1 gives the company power to determine the point at which the communication-pipe shall enter the premises to be supplied.

No 2 requires that all lead pipes in direct communication with the company's system shall be uniform in thickness, and fixes the strengths—the weight being taken as the guide.

Internal diameter in inches.	Weight in lbs.		Thickness in inches.	Safe head of water in feet.
	Per yard.	Per foot.		
$\frac{3}{8}$ = ·375	5	1·67	·1002 = $\frac{3}{16}$	622
$\frac{1}{2}$ = ·50	6	2·0	·1873 = $\frac{3}{16}$	460
$\frac{5}{8}$ = ·625	$7\frac{1}{2}$	2·5	·196 = $\frac{3}{16}$	385
$\frac{3}{4}$ = ·75	9	3·0	·202 = $\frac{3}{16}$	330
1 = 1·0	12	4·0	·212 = $\frac{3}{16}$	260
$1\frac{1}{4}$ = 1·25	16	5 3	·230 = $\frac{1}{4}$	226

The weight is calculated on a basis of 712 lbs. to the cubic foot, and the strength upon a mean ultimate cohesion of 2000 lbs. per square inch, allowing a factor of safety of $7\frac{1}{2}$.

The weights adopted by various water companies, as might be expected, vary considerably, on account of the different pressures to which the pipes will be subjected.

The following are the weights, per lineal yard in lbs., required by various companies:—

Name of company.	Internal diameter of pipe in inches.					
	$\frac{3}{8}$ in.	$\frac{1}{2}$ in.	$\frac{5}{8}$ in.	$\frac{3}{4}$ in.	1 in.	$1\frac{1}{4}$ in.
London Companies ...	5	6	$7\frac{1}{2}$	9	12	16
Kent	—	5	7	9	12	—
West Surrey	4	$5\frac{1}{2}$	—	9	14	20
Caterham...	5	6	8	10	14	—
Colne Valley	5	7	9	11	16	—
Sevenoaks and Tonbridge	—	5	7	9	12	15
Norwich	5	7	9	11	16	$22\frac{1}{2}$
Sheffield	5	7	9	11	16	$22\frac{1}{2}$
Market Harborough ...	5	6	$7\frac{1}{2}$	11	16	20
Glasgow (Loch Katrine)	—	7	—	10	14	18

No. 3 allows the consumer the option of lead, copper, or

wrought-iron, for internal pipes, except when in contact with the ground, when the company may insist on lead being used.

No. 4 limits the consumer to one communication-pipe. This is an important regulation.

No. 5 requires each house supplied by the company to have its own communication-pipe, except in the case of a block of buildings belonging to one owner, who pays the water-rates for them.

It frequently happens in rural districts that the undertakers are asked to allow a communication-pipe to a property to be tapped for the benefit of another property (the respective owners having agreed between themselves). This should never be permitted.

No. 6 prohibits any communication between the pipes or fittings of any two premises, except in the case provided for in the last regulation.

No. 7 provides that the connection of the communication-pipe with the company's pipes shall be made by the company at the cost of the consumer, the connection to be made by means of a "sound and suitable brass-screwed ferrule or stop-cock with union," having a clear waterway of not less than that of a ½-inch pipe.

No. 8 requires that every pipe external to the house, including the portions of pipes laid in external walls, shall be of lead; the joints to be "plumbing" or "wiped" joints.

No. 9 guards against possible pollution to the water in the consumer's pipes, and thence to the water in the company's pipes, from the consumer's pipes being "laid or fixed through, in, or into" any drain, ashpit, etc. Where such drain, ashpit, etc., is in the unavoidable course of the pipe, the pipe must be protected by passing it through a cast-iron pipe or jacket of sufficient length and strength and of proper construction. When the water is turned off from any part of the system a partial vacuum is formed, and any liquid matter in proximity to a faulty pipe or leaking joint would be sucked into the pipe, and might

be the cause of dissemination of disease throughout the whole system.

No. 10 requires that all pipes laid in open ground shall be laid at a depth of at least 2 feet 6 inches below the surface, and provides for proper protection against frost in exposed situations. A depth of 2 feet is frequently inserted in waterworks regulations, which is probably ample in this country.

No. 11 prohibits any communication between the pipes and any receptacles for rain-water.

No. 12 provides for the insertion of a "sound and suitable screw-down stop-valve," either at or near the point of entrance of the communication-pipe into the premises, or within the premises, at the option of the consumer. If placed in the ground, such stop-valve to be protected with a proper cover and guard-box.

For the reasons stated in Chap. XX., it is better to have the stop-cock fixed outside, so as to be under the immediate control of the undertakers. The principal objection, from the consumer's point of view, is that it is less accessible in case of burst pipes or other accidents, and entails the use of a loose key, which is liable to be mislaid.

No. 13 deals with cisterns, requiring that they shall be made water-tight, properly covered, placed in such a position that they can be easily inspected and cleansed, and that each cistern shall be provided with a sound and suitable "ball-tap" of the valve kind.

It is evident that if a cistern which is filled automatically is unsound, the waste of water must be constant. The provisions as to covering and cleansing allude to the possibility of pollution in a similar manner to that explained in connection with regulation No. 9.

No. 14 prohibits the use of overflow or waste-pipes other than "warning-pipes," to cisterns; and

No. 15 requires that all "warning-pipes" shall discharge at such a point that any flow may be readily ascertained by the officers of the company. The position of such

"warning-pipes" not to be altered without due notice to and the approval of the company.

These regulations are of the greatest importance, and should be strictly enforced. The old practice of allowing overflow pipes to empty directly into the drains was a prolific source of waste. In the case of the ball-tap being out of order, the waste might continue for months without being detected. With a "warning-pipe," which consists of a short pipe passing directly through the wall into the air, with an open mouth, the case is different; any waste is speedily detected, and the inconvenience caused by a constant stream of water flowing down the face of the wall of the house, causes the occupier to take prompt steps to remedy the defect.

No. 16 prohibits the use of buried or excavated cisterns. Waste from such cisterns would not only be non-apparent, but would be difficult of detection.

No. 17 forbids the use of wooden receptacles not having proper metallic linings, *e.g.* water-butts. This regulation has the double object of preventing waste and avoiding pollution.

No. 18 requires the use of sound and suitable draw-taps, which must be of the "screw-down" kind.

Draw taps are divided into two classes, "plug-taps" and "screw-down" taps. In plug-taps the spindle or plug simply revolves in the tap, without rising or falling; a horizontal hole through the plug being made to connect or disconnect the inlet and the outlet to the tap by revolving the plug. This form of tap has no washer. The objections to the plug-tap are twofold, the most important being the sudden check which is given to the momentum of the body of water behind it, when the tap is closed. An illustration of the enormous strain upon a system caused by the use of plug-taps is attributed to Mr. A. R. Binnie (*Builder*, July 7, 1894, p. 3). In this experiment the pressure on a $\frac{3}{4}$-inch pipe, 114 feet long, and branching off a supply main, and furnished at the end with a plug-cock measuring 0·152 of an inch, was at the branch 120 lbs., and at the open cock

itself 20 lbs. On the cock being shut quickly, those pressures were for the moment found increased to 220 lbs. at the branch, and 550 lbs. at the cock. The second objection to the plug-tap is its liability to leak, on account of the rapid wear, necessitating the plug being ground, which can only be done by a mechanic.

"Screw-down" taps (Fig. 52, Chap. XX.) have a screwed spindle, at the lower end of which is a washer, which, when forced against its seat by turning the spindle, closes the inlet to the tap. When a tap of this kind commences leaking, the old washer should be removed and a new one put in its place. This process is very simple and inexpensive, and can be performed by any intelligent person. The washers consist of leather, except for hot water, when vegetable fibre should be used. A tap invented by Lord Kelvin has been introduced within the last few years, in which the washer is constructed of gun-metal, and revolves upon its seat. In its earlier form it was not found to work satisfactorily under high pressure, but it has recently been much improved.

No. 19 refers to taps for "stand-pipes," and requires that they shall be of the "waste-preventer" kind, and be protected from injury by frost, theft, or mischief. With low-pressures automatically closing taps may be employed, but under high pressures they are rarely free from leakage. They are, in nearly all cases, open to the same objections as plug-taps.

No. 20 requires boilers, urinals, and water-closets to be served only through a cistern or service-box, and forbids the use of stool-cocks, or any direct communication between the company's pipes and such apparatus.

No. 21 requires the cistern supplying a "water-closet" to be fitted with a "waste-preventing" apparatus, capable of discharging not more than 2 gallons at each flush.

The desirability of altering this regulation being brought before the Local Government Board by several of the metropolitan sanitary authorities, the matter was referred to the London County Council, who again applied to the

Sanitary Institute for an opinion upon the subject. After much consideration and experiment, the Sanitary Institute reported as follows:—

"That Clause 21 of the Regulations under the Metropolis Water Act, 1871, should be altered to read, 'so constructed as to discharge not less than 3 nor more than $3\frac{1}{2}$ gallons of water at each flush.'"

The Local Government Board has, however, pointed out that such a recommendation was not within the purport of the Regulations referred to, which have for their object the prevention of waste, misuse, or contamination of water. The London County Council have agreed to make application to the water companies to amend the Regulations in the direction desired.

An unnecessary use of water is caused when water-closets adapted for use as urinals are fitted with waste-preventing cisterns discharging 2 gallons of water at each flush. For the latter use a much smaller flush would suffice, but there is no means of reducing the flush on such occasions.

No. 22 is similar to the last, and refers to urinals, but fixes the maximum flush at 2 gallons instead of 1 gallon.

No. 23 requires the "down-pipe" of a closet to have an internal diameter of not less than $1\frac{1}{4}$ inch, and if of lead to weigh not less than 9 lbs. to every lineal yard. The object of this, and Regulation 29, from the company's point of view, is not obvious.

No. 24 forbids any communication between the pipes supplying the company's water and any part of a water-closet, or any apparatus connected therewith, except the service cistern.

No. 25 prohibits the existence of any overflow pipe to a bath, unless it be constructed as a "warning-pipe." The remarks made in connection with Regulations 14 and 15 apply to this regulation, but to a modified extent.

No. 26 requires that the inlet shall be distinct from, and unconnected with, the outlet of a bath; that the inlet shall be above the highest water-level of the bath; and that the outlet shall be provided with a perfectly water-tight plug,

valve, or cock. These requirements aim at the abolition of baths having a combined inlet, outlet, waste, and overflow (the last being, however, prohibited by Regulation 25) at the bottom. These arrangements are very liable to get out of order, and water might easily escape directly into the drain without ever being noticed.

No. 27 requires that no alteration shall be made in any fittings in connection with the supply of water without two days' previous notice in writing to the company. Compare Waterworks Clauses Act, 1863, sec. 19.

No. 28 is for the protection of the consumer, where the communication-pipe is laid by the undertakers, and sets forth that no cock, ferrule, joint, union, valve, or other fitting, in the course of any "communication-pipe," shall have a less water-way than that of the communication-pipe.

No. 29 requires that all "warning-pipes" and other lead pipes of which the ends are open, so that such pipes cannot remain charged with water, may be of the following minimum weights :—

Internal diameter in inches.	Weight per yard in lbs.
½	3
¾	5
1	7

No. 30 defines "communication-pipe" as being the pipe which extends from the district-pipe or other supply-pipe of the company up to the "stop-valve" prescribed in Regulation 12.

No. 31 imposes a penalty of £5 on any person contravening these Regulations.

No. 32 empowers an authorized officer to act for the company.

No. 33 states that all existing fittings approved by the company shall be deemed to be prescribed fittings under the Metropolis Water Act, 1871.

CHAPTER XXII.

STORAGE OF RAIN-WATER.

As the rainfall is stored on a large scale by impounding reservoirs for the purposes of providing a supply of water for domestic and other purposes to towns or a series of villages, so also it may be collected and stored on a small scale for the use of isolated dwellings. In the latter case, roofs or prepared areas of ground take the place of the catchment area; the impounding reservoir is replaced by metal, masonry, brickwork, or concrete tanks, which also constitute the service-tanks; and filter-beds of adequate dimensions have also to be provided. Storm overflow must not be omitted, but in this case with the sole object of preserving the purity of the water in the tank. The principles involved in the necessary calculations are likewise similar, the supply depending upon the available rainfall and the area of the collecting surfaces.

Rain-water from the roofs of houses is usually collected by means of gutters, with the immediate object of preventing it from flowing down the walls and rendering them damp. It is also usually stored in butts or tanks for washing purposes, when the principal supply is of a hard nature, and for other purposes when the latter is limited in quantity. It is rarely, however, employed for dietetic purposes, except as a last resource, when no other supply is forthcoming. In fact, the prejudice against it is so great that people frequently prefer to it the water of wells or springs which they know to be polluted. Another reason, perhaps, is the general ignorance of the capabilities of a comparatively

small collecting surface in affording a regulated daily supply through the use of storage capacity properly proportional to the particular area of surface and the available rainfall.

As stated in Chapter IX., the amount of rainfall varies considerably in different parts of the country, from 40 to 70 inches per annum on the western coast, from 30 to 40 inches on the southern coast, and from 20 to 30 inches on the eastern coast—the average rainfall over the whole of Great Britain being about 33 inches. Further, it was stated that the rainfall at the same place varied considerably in different years—from 45 per cent. above the average to 33 per cent. below the average. There is, however, another most important variation in the rainfall, when corresponding months in different years are compared, which plays a most important part in the calculation of the necessary amount of storage-capacity for roof or similarly collected supplies. In this case there is no percolation, and the rainfall passes directly into the storage tanks, the flow not being subject to regulation by the catchment area.

An examination of the table given on p. 166, taken from "Sanitary Engineering," by Baldwin Latham, M.I.C.E., F.G.S., will show that, although the monthly averages are fairly constant when the observations extend over several years, the individual falls vary from 204 per cent. above the average, as in December, 1876, to 90 per cent. below the average, as in September, 1865.

The theoretical storage capacity should be such that the tank should contain a sufficient quantity of water at the commencement of a drought so as to afford the calculated daily supply until it is over; also to be able to store the surplus of the rainfall above the consumption during wet weather. Or, in other words, that there shall always be a sufficient supply of water in the tank—provided that only the calculated amount is abstracted from it daily—and that the tank shall never overflow. The lowest annual rainfall must be taken as the basis upon which the daily supply is to be calculated. In the above table the lowest annual rainfall was 20·26 inches, which, if properly stored (excluding

RAINFALL AT CROYDON, COMPILED FROM OBSERVATIONS MADE BY MR. GEO. CORDEN, CROYDON.

Rain-guage, 154·6 O.D. "Sanitary Engineering," 2nd edit., by Baldwin Latham, M.I.C.E., F.G.S., pp. 54 and 55.

Month.	Monthly average.	1861	1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877
January ...	2·95	·49	2·10	2·87	1·34	3·45	4·51	3·12	4·31	2·91	1·43	2·87	5·54	4·08	1·15	3·49	1·04	5·53
February ...	1·70	2·37	·48	·61	1·32	1·82	5·11	1·24	1·22	2·46	1·72	1·19	1·07	1·69	1·83	1·04	2·05	1·70
March ...	1·82	2·72	3·26	·79	2·95	1·05	2·08	2·58	1·08	1·52	1·84	1·50	2·13	1·55	·55	·65	2·57	2·15
April ...	1·54	·61	2·27	.61	·64	·27	2·04	1·75	1·92	1·16	·42	3·23	1·23	·63	1·87	1·74	1·67	4·10
May ...	1·82	·93	3·45	1·50	2·69	3·40	2·17	1·52	·76	3·20	·86	1·00	3·05	1·21	·86	·95	·93	2·38
June ...	1·93	1·90	3·06	3·59	·80	1·99	3·05	1·85	·35	1·34	·20	2·68	1·96	3·41	2·54	2·26	·99	·87
July ...	2·25	2·78	2·09	1·16	·99	3·33	1·48	4·21	2·23	·66	2·24	2·89	3·29	2·27	1·18	4·50	·34	2·58
August ...	2·15	·54	3·36	2·10	1·19	3·69	3·16	2·08	2·98	1·24	1·86	·81	2·24	2·53	2·41	·90	2·75	2·70
September ...	2·69	2·16	1·96	5·16	3·09	·27	4·07	2·57	1·71	3·32	2·44	5·00	1·63	2·30	2·49	2·90	3·07	1·65
October ...	2·93	1·03	4·92	2·22	1·26	7·20	1·33	1·89	2·37	1·66	4·24	1·17	5·24	3·14	4·83	4·07	1·31	1·97
November ...	2·53	5·41	1·37	2·08	3·46	3·14	1·38	·62	1·15	2·53	1·89	·55	3·50	2·54	2·59	3·15	2·67	4·94
December ...	2·44	1·29	2·02	2·88	·53	1·80	2·00	1·61	4·50	3·38	3·03	1·65	4·39	·36	1·80	1·22	7·43	1·61
Total annual average.	26·75	22·23	30·34	25·57	20·26	31·41	32·38	25·04	24·58	25·38	22·17	24·54	35·27	25·71	24·10	26·87	26·82	32·18

loss by evaporation) would supply a monthly consumption equal to 1·69 inches. The storage capacity necessary to equalize the rainfall in order to furnish this supply may be calculated by the method given in Chap. XIII., either graphically or arithmetically.

The calculation of storage capacity based upon the rainfall for 1864, given in the table above, is as follows:—

Month.	Rainfall.	Consumption.	Algebraical sum.	Accelerated sum.	A
January ...	1·34	1·69	− ·35	− ·35	1·25
February ...	1·32	1·69	− ·37	− ·72	·88
March ...	2·95	1·69	+ 1·26	+ ·54	2·14
April ...	·64	1·69	− 1·05	− ·51	1·09
May ...	2·69	1·69	+ 1·00	+ ·49	2·09
June ...	·80	1·69	− ·89	− ·40	1·20
July ...	·99	1·69	− ·70	− 1·10	·50
August ...	1·19	1·69	− ·50	minimum − 1·60	0·00
September	3·09	1·69	+ 1·40	− ·20	1·40
October ...	1·26	1·69	− ·43	− ·63	·97
November...	3·46	1·69	+ 1·77	maximum + 1·14	2·74
December...	·53	1·69	− 1·16	+ ·02	1·58

To give an equalized monthly supply equivalent to 1·69 inches would, therefore, require a minimum storage capacity for 1·60 + 1·14 = 2·74 inches, provided that the tank contained at the commencement of the year a quantity of water equivalent to 1·60 inches.

The column marked A in the above table shows the depth of rainfall corresponding to the quantity of water contained in the tank at the end of each month, under these conditions. This is assuming that the rainfall is uniform throughout each month, but as this is not usually the case, and the bulk of it may fall during the first day or two, it is necessary to increase the storage by one month's consumption = 1·69 inches, making the total storage capacity equal to 4·43 inches, or about 22 per cent. of the total annual rainfall. Mr. Thomas Box ("Practical Hydraulics") gives

one-fourth of the total annual rainfall as the minimum storage capacity, and this may be taken as a safe rule.

There are several rules for calculating the supply of water obtainable from a given collecting surface and annual rainfall, three of which are given here:—

1. Multiply the area in square feet by half the annual rainfall in inches = the quantity of water in gallons approximately (Parker's "Practical Hygiene").

2. Multiply the area covered by the roof in square feet by the average annual rainfall, also in feet, and divide the result by 100 = the average supply in gallons per diem, for a very dry year (J. Wallace Peggs, "Transactions," Sanitary Institute, vol. xiv.).

3. Multiply the lowest recorded rainfall in feet by the collecting area in square feet by ·015 = the average number of gallons per day, including a small allowance for loss in the collection ("Water, its Composition, etc.," by Joseph Parry, C.E.).

The following table, by W. Sowerby Wilson, F.R.M.S., shows the daily yield of water from a roof with varying rainfall: area of house, 10 feet by 20 feet, or 200 square feet:—

Mean rainfall.	Loss from evaporation.	Requisite capacity of tank.	Mean daily yield of water.	Mean daily yield of water in wettest year.	Mean daily yield of water in dryest year.
Inches.	Per cent.	Cubic feet.	Gallons.	Gallons.	Gallons.
20	25	100	4·3	6·7	3·2
25	20	135	5·7	7·5	3·9
30	20	145	6·8	9·4	4·5
35	20	155	7·9	11·0	5·0
40	15	165	9·7	13·1	7·2
45	15	170	10·9	14·2	8·6

For any other size of roof or amount of rainfall, the numbers will be proportional.

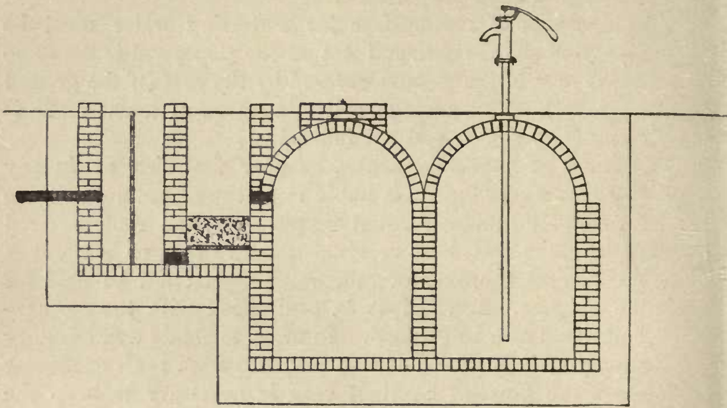
The area of roof-surface for collecting water must be measured on the flat, and not on the slope, and is the same as the area of the ground covered by the roof (if the ground be level). The average collecting area of house-roofs is about sixty square feet per individual.

Roofs of houses in towns, or near factories, or in any situation where the air is liable to pollution, are not suitable for collecting water for dietetic purposes, and roofs covered with thatch, felt, lead or zinc—the two last, on account of the solvent property of rain-water,—must not be used for the purpose. Lead pipes in connection with the storage-tank must also be avoided. In order to obtain a satisfactory supply of water for domestic purposes from roofs or similar areas, the greatest constant care is necessary to keep the roofs and gutters clean, and to remove all bird-excrement, etc.

The first portion of the rainfall collected from roofs, especially after a long period of dry weather, is usually of an impure nature, on account of the soot and other matters which have had time to accumulate. In order to prevent this portion from entering the storage tank, mechanical appliances, known as "rain-water separators," have been devised. These consist of vessels into which the rainfall is directed before passing into the storage tank, and which are so constructed as to collect the first portion of the flow, and when full to cant over, emptying their contents to waste, and at the same time placing the flow of water from the roof in direct communication with the storage tank. When the flow has ceased they return automatically to their original position.

The rain-water may be stored in overground or underground cisterns, or reservoirs. The former have the advantage of enabling the water to be drawn direct by means of a tap, but are generally more expensive, and the water is subject to changes of temperature. The underground reservoir necessitates pumping, and is more liable

to permit of pollution. The water should be strained



Section C D

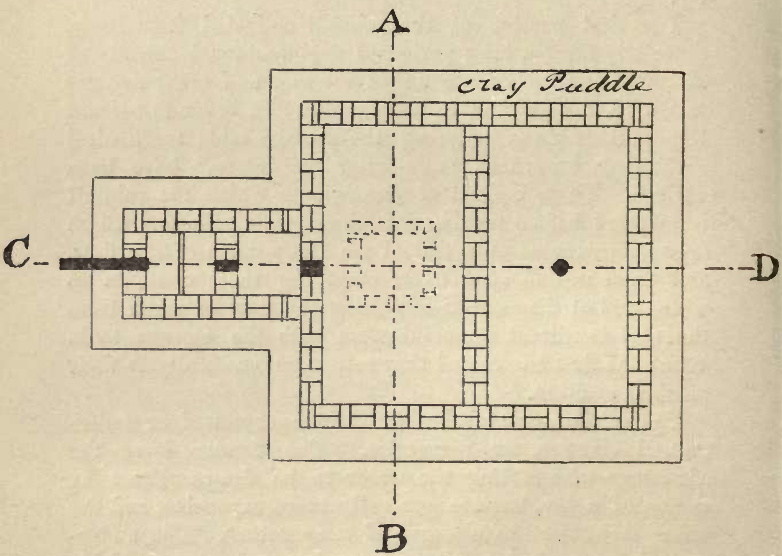
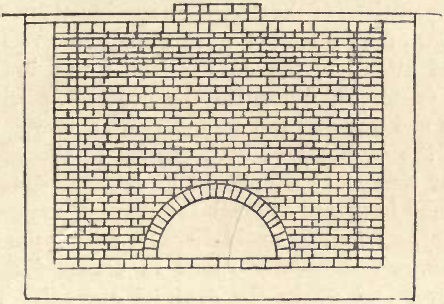


Fig. 55.

through a copper strainer to keep back leaves, etc., and should be filtered before admission into the storage tank. The filtering material may be sand, polarite, or other suitable substance. The tank should be efficiently ventilated; have a sufficient covering of earth so that the water may be kept at an equable temperature; and should be, if possible, provided with a wash-out valve for cleansing purposes. Fig. 55, is an illustration of a brick underground tank, with strainer and filter-bed, to contain 2500 gallons, designed for a small isolation hospital.



Section A B

FIG. 56.

Where the roof surface is insufficient, a small area of ground may be fenced off, and either underdrained by means of agricultural tiles, or the surface may be covered with tiles or concrete, and the rain-water falling upon it taken by means of pipes to a storage-tank.

CHAPTER XXIII.

SPECIFICATIONS AND ESTIMATES.

The preparations of the drawings, specifications, and general conditions of an intended work should receive the greatest care and attention, the descriptions being in detail and clearly expressed, otherwise the contractor will construe them in one way and the engineer in another. It is therefore in the interests of both parties to the contract that sufficient time and care should be taken in drawing up the clauses and in giving as much information as possible to the contractor. This will avoid disputes during the progress of the work, which usually result in claims for extra payments over and above the contract amount. The bill of quantities showing the amount of work to be performed under each item of the specification is either prepared by the engineer or by a quantity surveyor, for which it is customary to allow from ½ to 1 per cent. on the amount of the accepted tender. This is charged through the bill of quantities, and repaid or transferred to the engineer or quantity surveyor by the contractor. It is not a desirable arrangement for the engineer to have any monetary transactions with the contractor, and it would undoubtedly be an advantage where the quantities are taken out by the engineer for this payment to be made direct to him by the person or persons for whom the work is being performed.

The following specification for cast-iron pipes will act as a guide to the preparation of contracts for such works, at the same time giving an insight into the style and method usually adopted in the preparation of specifications

generally. The general conditions in this case are embodied in the specification, and are not kept distinct, as is usual in large contracts for engineering works.

Rural Sanitary District of ——.

Cast-iron Pipes, Irregulars, and Special Castings.

Specification to be observed by the contractor for the supply of ordinary iron pipes, irregular iron pipes, and special castings, to the Waterworks Department of the Local Authority of the Rural Sanitary District of ——.

1. The cast-iron pipes, from 3 inches to 12 inches in diameter, are to be in 9 feet lengths, and the 2-inch pipes are to be in 6 feet lengths, in each case exclusive of the socket. The whole or any portion of the above sizes to be spigot and socket, or half-turned and bored joints as may be directed to be supplied, and to be of the following weights, except when otherwise ordered.

Diameter in inches.	Length, exclusive of socket.	Weight, including socket.			Diameter in inches.	Length, exclusive of socket.	Weight, including socket.		
ins.	ft.	cwts.	qrs.	lbs.	ins.	ft.	cwts.	qrs.	lbs.
2	6	0	1	19	8	9	3	2	10
3	9	1	0	7	9	9	4	2	6
4	9	1	1	15	10	9	5	0	3
5	9	2	0	2	11	9	5	2	1
6	9	2	1	14	12	9	6	2	22
7	9	3	0	19	—	—	—	—	—

2. Any pipes which deviate more than 3 per cent. from the stipulated weights will be rejected. The whole of the pipes are to be manufactured and afterwards tested by hydrostatic pressure, by and at the expense of the contractor.

The test pressure to be equal to a column of water 600 feet high, and such pressure shall be maintained in each pipe at least two minutes, previous to which the connection between the pump and the testing-machine is to be cut off. Each pipe, while under the pressure, shall be rapped from end to end with a hand-hammer 4 lbs. in weight, so as to discover any sandy, porous, or blown places. The pipes will be again proved by and at the expense of the authority, after they have been delivered at the place required. Any pipe which shall be found to be imperfectly coated, or in which any imperfections shall appear, or wherein any sand or air-holes shall appear to have been plugged up, or which shall not agree with the terms of the specification, will be rejected.

3. The irregular pipes and special castings are to include all branches, elbows, thimbles, clips, cant socket-pieces, hydrant, valve, meter, and stop-tap covers fitted as per pattern, also all flange and other special castings, samples of which may be seen on application at the waterworks offices.

4. The straight pipes are to be cast in dry sand moulds vertically, with the sockets downwards, and the curved pipes in loam or dry sand in close boxes; the castings are to be made without the use of core-nails, chaplets, or thickness pieces, or any substitute for the same, and the contractor is to provide turned iron patterns, boxes, core-bars, and barrels for making all straight pipes, the flanges, spindles, sole plates, and cores of which are to be accurately turned, faced, bored, truly fitted and joined. The sand must be sufficiently fine and fresh to produce a smooth and perfect surface, and all the moulds and cores are to be properly black-washed and carefully dried. Great care is to be taken in preparing and drying the cores in order to ensure a smooth surface to the pipes internally.

5. All pipes of 5 inches diameter and under will be allowed to be cast at an angle of not less than 45 degrees from the horizontal. The pipes of each size respectively are to be of uniform bore and thickness of metal through-

out their respective length, and without any belts. The castings are to be free from scoriæ, sand-holes, air-bubbles, cold-shuts, laps, washers, and all other imperfections; and the pipes are to be truly cylindrical in the bore, straight in the axis, smooth within and without, and internally of the full specified diameters, and they shall have their inner and outer surfaces as nearly as possible concentric. An increased length of at least 6 inches is to be cast on the spigot end of each pipe, such increased length being afterwards cut off in a lathe to the specified size. All pipes are to be perfectly dressed and cleansed, so that no lumps or rough places are left in the barrels or sockets. The contractor will be charged with and must pay and defray any and all losses, charges, and expenses to or for which the Local Authority or their Committee may be put, or be liable by reason of any neglect with respect to the forms and sizes of the sockets and spigots. And for the better prevention of chills, uneven shrinkage, and cracks consequent thereon, the contractor must undertake that the pipes shall not be removed too hastily from the moulds, or be laid while hot upon cold or damp earth, or be exposed while in a heated state to wet or inclement weather.

6. Special precautions are to be taken in obtaining and maintaining the proper standard of quality of the mixture of iron, and in the melting of it. All the metal used shall be made from mine pig, without any admixture or proportion of cinder iron or other iron of inferior quality; and the whole to be of the best tough, close-grained grey iron, to be remelted in a cupola or air-furnace. Whenever any castings are made, as many test-bars are also to be cast from the same metal as may be required by the Local Authority or their engineer. The test-bars are to be 2 inches by 1 inch by 3 feet 6 inches long, placed horizontally upon the narrow width, supported on bearings 3 feet apart, and to be capable of sustaining without breaking a weight of not less than 30 cwt., gradually applied in the centre of the bar, and producing a deflection of not less than from ·3 to ·4 of an inch. The contractor is to provide in his works, under cover and

protection, suitable and approved machines for testing the test-bars to the full satisfaction of the engineer before he will be allowed to commence work under this contract.

7. All pipes which are ordered to have half-turned and bored joints are to be cast with such increased thicknesses of metal at the spigot and socket ends as will allow them to be so turned and bored and otherwise finished as that the spigot end of any pipe shall enter to the bottom and fit perfectly in the socket of any other pipe, and that when driven together, the whole of the turned and bored portions are in complete contact with each other, and form a perfectly water-tight joint, without the aid of any cement, lead, paint, or other substance. The turning and boring is to be executed after the pipes are coated as hereinafter specified. The turned portion of the spigot is to be $\frac{3}{4}$ of an inch in length, with a taper of 1 in 32, the socket having a similar taper to suit it. The spigot and socket joints, when so ordered, are to have a recess cast around the inside of the socket, and a bead on the spigot according to the directions of the Local Authority or their engineer. The sockets of all pipes under 4 inches in diameter are to have an allowance of $\frac{1}{4}$ of an inch, and above 4 inches in diameter an allowance of $\frac{3}{8}$ of an inch for the lead-joint.

8. Each pipe is to have a consecutive number, year (initials of authority), and maker's name cast on the socket, in the same order, as specified on each order for goods, and any pipe found to be defective under the tests applied shall not have its number replaced, such number on the defective pipe being disfigured by a chisel-cut.

9. All pipes, irregulars, and special castings are to be heated in a stove to a temperature of 300° Fahr., and then dipped into a solution known as Dr. Angus Smith's, which must be of a similar temperature to the pipes.

10. All irregular pipes and special castings are to be made according to particulars to be furnished hereafter by the engineer; but all patterns and moulds that may be required in connection with the above are to be provided at the cost of the contractor.

11. The engineer or any other person the Local Authority may appoint will be empowered to reject any pipe or other casting he may consider defective, unsound, badly varnished, of inferior quality, or not in accordance with the order, and the same is to be removed by the contractor after notice has been given to him, at his own expense; and if not removed within three days after a written notice has been served upon him, the whole or any portion of such defective material may be removed by the Authority at the contractor's expense.

12. Orders signed by the engineer or other authorized person for the Local Authority will be given from time to time for such descriptions of pipes and other articles as may be required under the contract, to be delivered within the following periods of time:—

Straight pipes, 2 to 8 inches in diameter, inclusive: 100 within 14 days, and 100 per week afterwards.

Straight pipes, 9 to 12 inches in diameter, inclusive: 50 within 14 days, and 50 per week afterwards.

Branch pipes, and other irregular or special castings, 2 to 8 inches in diameter, inclusive: 10 within 14 days.

Branch pipes, and other irregular or special castings, 9 to 12 inches in diameter, inclusive: 10 within 14 days.

13. Should the contractor fail to deliver the pipes, irregulars, or special castings as required, the Local Authority shall have power to determine or cancel the whole or any portion of the contract, or to order elsewhere any goods not supplied, and the difference in cost between the goods so supplied and the contract price may be charged to the contractor, or deducted from any amount due or to become due to him under the contract.

14. The pipes and all other castings are to be delivered to the ——— station of the ——— Railway Company, when delivered by rail, or at the waterworks yard when delivered by road or canal, free of charge to the Local Authority, and the said Authority reserve to themselves the right to weigh all pipes and castings on their own weighing machines, and to pay for same according to such weights.

15. Should any dispute or difference of opinion arise as to the meaning or intention of this specification or of the contract, the interpretation of the same by the clerk to the Local Authority or other person to be agreed upon before entering on this contract, shall be binding and conclusive on both parties in the matters to which such interpretations shall refer.

16. The Local Authority do not bind themselves to accept the lowest or any tender, and reserve to themselves the right to divide and accept part or parts only of a tender.

17. The contractor must enter into a bond for the due fulfilment of the contract under the penalty of £100, such bond and agreement containing the written terms and stipulations to be prepared by the clerk to the Authority, and sealed by the said Authority.

18. Payments will be made monthly after the next succeeding meeting of the Authority, if accounts are sent to the engineer on or before the ——— day of any month.

19. Tenders are to be made on the annexed form, four prices per ton to be given, viz.:

(1) For ordinary cast-iron pipes—

a. Spigot and socket.

b. half-turned and bored.

(2) For irregular castings.

(3) For all other special castings.

Form of Tender.

Address ——,
Date ——.

To the —— Rural Sanitary Authority.

Gentlemen,

I beg to tender for the following *pipes, irregulars, and other castings*, as per specification, for twelve months from the above date.

	£ s. d.
Ordinary cast-iron pipes (spigot and socket) per ton	
Ordinary cast-iron pipes (half-turned and bored) per ton	

Irregulars as under—

Taper or reducing pipes	per ton
Thimble or other branches	
Saddle branches	
Bends, elbows, and cant sockets ...	
Thimbles or collars	
Clips	
Cap ends	
Duckfoot bends	
Flange pieces (various)	
Blank flanges	

Special Castings as under—

Hydrant covers, as per sample, fitted	per ton
Meter " " " "	
Stop-tap " " " "	
Valve " " " "	
Air-valve " " " "	
Meter caps " " " "	
False spindles of various lengths ...	

Signed ——,

Address ——.

In preparing estimates of work to be performed, careful consideration must be given to the district in which the work is to be executed; and the correct estimation of the prices requires considerable experience of practical work. The following statement is the actual cost of laying a 3-inch main along a main road, giving the details and

prices of each item. All estimates should be taken out in a similar manner.

DISTANCE 117 YARDS—3-INCH MAIN.

No.		Tons.	cwts.	qrs.	lbs.		£	s.	d.
39	3-in. pipes ...	2	1	—	—	at £5 per ton ...	10	5	0
1	5 by 3-in. branch	—	1	1	14	at 10s. 1½d. per cwt.		13	10
2	3 by 3-in. branch	—	1	—	—	„ „		10	1
1	3-in. bend ...	—	—	2	7	„ „		5	9
1	3-in. valve ...	—	—	—	—	... ...	1	16	1
1	Valve cover ...	—	—	2	7	at 16s. 1¼d. per cwt.		9	2
—	Lead	—	—	1	—	at 12s. per cwt. ...		3	0
—	Yarn	—	—	—	2	at 2d. per lb. ...		0	4
—	Coal	—	1	2	—	at 9d. per cwt. ...		1	2
—	Cement	—	1	—	—	at 2s. per cwt. ...		2	0
—	Hauling ...	2	—	—	—	at 1s. 3d. per ton ...		2	6
	Wages paid for labour ...					... ...	7	0	0
							£21	8	11

CHAPTER XXIV.

WELLS.

WELL-SINKING on a large scale for rural water-supply is of rare occurrence, and the details, which necessitate an extensive knowledge of practical geology, are so numerous and complicated that the subject cannot be dealt with satisfactorily within the limits of this book. The principles and methods have been comprehensively dealt with in several standard treatises upon the subject, and to these the student must be referred. As, however, wells may be said (and often unfortunately so) to form the most frequent source of supply for villages, groups of houses, and isolated dwellings in country districts, some details upon this branch of the subject will be given here.

Wells may be classed under three heads—

1. Shallow or surface wells (Fig. 56).
2. Deep wells (Fig. 57).
3. Artesian wells (Fig. 58).

In Chapter II., whilst referring to the disposal of the rainfall, it was stated that "a portion of the rain sinks into the ground and forms the underground reservoirs in which wells are sunk, issuing again at the lowest lip as springs." When a porous stratum, such as sandstone or chalk, which has the power of retaining water in its pores or fissures, is superposed upon an impervious stratum, such as clay, the porous stratum will be saturated, and the water held up as in a basin, to a plane inclining towards the lowest lip, which is generally the outcrop of the impervious stratum.

If the porous stratum is adjacent to the surface of the ground, the plane of saturation is generally at no great depth; and if a well is sunk to a point below this plane, water will collect in it and stand at the level of the plane. This constitutes a shallow well. Under these circumstances the level of the plane of saturation is very variable, being rapidly affected by the rainfall. As the rainfall in its

FIG. 57.

passage into and through the ground, on account of its highly solvent nature, takes up and carries with it any impurities, more particularly of an organic nature, which it meets with on its way; and as the distance through which it has to pass before flowing into the well is usually very short, shallow wells are dangerous sources of water supply for domestic purposes. It is only in such cases as where

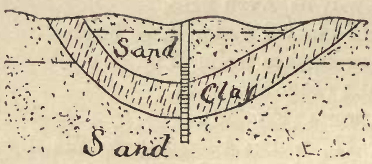


FIG. 58.

the well is in an isolated position, in a rural district, and sufficiently removed from any possible source of pollution, that its use in this connection should be permitted. Wells of this description must be properly walled in or steined with stone, brickwork, or concrete, and in the two first cases the joints should be made thoroughly watertight with hydraulic lime-mortar or cement. The top of the wall

should be protected by a raised kerb, where a bucket is used for drawing the water, and fitted with a proper cover, or where the water is drawn by means of a pump, the top of the well should be domed or flagged over. The bucket system has an advantage over the pump in affording greater facilities for cleaning out the well, which should be done once a year. On the other hand, the pump-well, through being permanently covered over, is less liable to pollution from the surface. As the water in shallow wells is usually of a soft nature, the suction pipe of the pump should not be composed of lead.

Deep wells are those which are sunk through an impervious stratum to a porous or water-bearing stratum

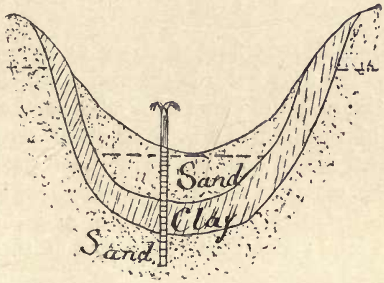


FIG. 59.

beneath it, the water being held up in the latter by an impervious stratum underneath it again. The terms "deep" and "shallow," in connection with wells, do not, therefore, refer to the actual depth of the well, and a shallow well may, in fact, be deeper than a deep well. Deep wells, if properly constructed, constitute excellent sources for domestic supply. The rainfall which feeds them is collected upon the exposed surfaces of the water-bearing stratum, which are usually situated at a distance from the site of the well, and becomes purified in its passage through the ground. On account of its prolonged contact with strata at some depth below the surface, deep well-water usually contains a considerable

amount of mineral matter in solution which it has taken up during its passage; this gives it a hard character. Deep wells have also the advantage of being slowly affected by the rainfall, and the level of the water in them is fairly constant. It is of paramount importance that any percolation from the beds above the impervious bed through which the well is sunk should be effectually prevented. This is done in a manner similar to that described for shallow wells. The precautions at the surface are the same in both cases. The level at which the water will stand in a "deep well" depends upon the elevations of the collecting ground and the line of overflow, the principles upon which it depends being the same as already described in reference to the virtual slope or hydraulic mean gradient of water flowing in pipes.

There is a continuous flow of water in saturated strata from the collecting area towards the outlet, which is usually the bed of a river, or the shore of a lake, or the sea. The surface-level of this moving body of water, which may be called its virtual slope, depends upon the resistance of the materials which compose the strata through which it flows, the presence of faults or dislocations, and the physical features of the land; technically, the first of these includes the other two.

Should the point selected for sinking a deep well be situated beneath the virtual slope of the water in the saturated beds, then, when these beds are reached, the water will rise to the top of the well and (were it not for the resistance of the air) above it to the virtual slope at that point. This would constitute an artesian well. The name is derived from Artois, a province of France, where this form of well was first brought into general use. It will be evident to the student that the artesian well is only a special condition of the deep well. As in wells of this description the water rises of its own accord, either so as to overflow, or to within a certain distance from the surface, it is only necessary to dig the well to a sufficient depth to allow of the pump being fixed within 30 feet of the lowest level to

which the water rises, and to afford sufficient storage capacity. The remaining portion may consist of a small perforation bored down to the required depth, which is lined with an iron tube, or occasionally left unlined when it passes entirely through rock.

The Abyssinian or tube-well (Fig. 60) is economical and satisfactory where the ground is suitable, and where the water stands, or by deeper sinking may be made to rise within 30 feet of the surface of the ground. This well consists of iron tubes from 1¼ inch diameter, in sections, which are driven into the ground, the bottom section, which is perforated, having a steel point to enable it to penetrate. As the tube is forced down into the ground, a fresh section is screwed on to the upper end of the last tube until the desired depth is reached. A pump is then fixed to the top of the composite tube, and the work is complete. An advantage possessed by this form of well is that it can usually be withdrawn and driven again in a new situation. Percolation of surface-water between the lining of the well, and the ground through which it is driven, is also prevented.

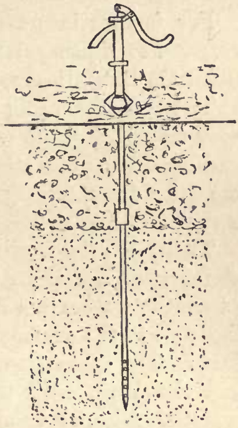


FIG. 60.

The following is an estimate for an Abyssinian tube-well in gravelly ground, where driving-plant is provided and a well-driver, sent by the contractors to superintend fixing, labour being provided by the Authority.

Estimate.

Depth, 30 feet	£	s.	d.
30 feet $1\frac{1}{4}$-inch Abyssinian tube, hire of plant, and well-driver	4	18	0
3-inch Abyssinian column-pump, with foundation ...	2	15	0
Well-driver's time, travelling, say one day	0	10	0
Ditto, ditto, railway fares	1	1	0
Carriage and Cartage of Plant and materials	1	0	0
Labourer, 1 day	0	2	6
	£10	6	6

For further information upon this subject, the student is referred to a pamphlet published by Messrs. Le Grand and Sutcliffe, Bunhill-row, London, E.C.

The cost of digging wells depends upon the nature of the rock or soil through which the excavation has to be made, and upon the precautions which have to be taken to prevent the sides from falling in, and in dealing with the surface water.

There are two principal methods of constructing the steining of a well in treacherous ground. The first is to excavate to a certain depth, and then to build the lining of the well to the surface of the ground upon a wooden ring or kerb. The excavation is then continued for a further depth, and the kerb, with the cylinder of brickwork, or other material, allowed to sink. The walling is then continued again to the surface, the excavation and walling being carried on alternately until the required depth is reached. Iron cylinders in sections are also used, the principle being the same. The second method consists in under-pinning and building beneath each section of the steining as constructed.

Half brick rings are usually sufficient, especially when laid in cement.

The courses should break joints, and the bricks should be radiating.

It is always advisable to have a puddle or concrete backing to the lining of a well, especially near the surface.

CHAPTER XXV.

WELLS—*continued.* LEAD POISONING.

Specification of a well and other works required to be constructed for Mr. ——, on land adjacent to the main road leading from —— to ——, in the parish of ——, in the county of ——.

The works comprised in this contract are the excavation and lining of a well, and other works, as shown on the drawing (Fig. 61) attached to this specification, and hereinafter more particularly detailed and described.

The site of the well is shown on the aforesaid drawings, and the strata will probably consist of—

Alluvium	2 feet
Sand and gravel	4 „
Soft and hard marl	64 „
Sandstone	10 „

The well is to be excavated or sunk to a depth of 80 feet, and 4 feet 6 inches diameter in the clear inside the brickwork lining. The excavation is to be trimmed back of sufficient width for the lining and concrete backing, or 7 feet 6 inches in diameter where lining is inserted with concrete backing, and 6 feet in diameter where brickwork lining only is inserted; the remainder of the excavation, where lining is not found necessary, is to be made 4 feet 6 inches in diameter, and neatly trimmed to the circle.

The excavated material is to be removed by the contractor as part of this contract.

Blasting with explosives will be permitted, but no shots are to be fired within one foot of the sides of the excavation.

The brickwork lining is to be 9 inches in thickness, built solid in Portland cement mortar, and to consist of header and stretcher-courses, constructed in sections on the system known as "underpinning," but no section of the brickwork is to exceed one-fourth of the circumference, or 4 feet in vertical height as a maximum. Great care must be taken in measuring the height of the courses so as to avoid wide closing-joints. The brickwork is to be built in, as the

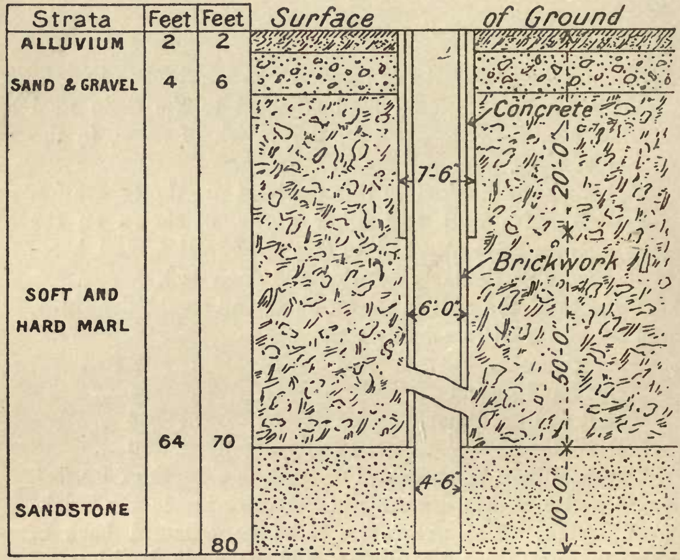


FIG. 61.

sinking proceeds, where the ground is not strong enough to stand alone. No vacant spaces are to be left behind the lining, but all such spaces must be filled in with fine cement. The lining is to be kept perfectly plumb, and worked from a radius-rod off the centre-line.

The ring of cement concrete backing to the brickwork is to be carried to a depth of 20 feet from the surface, and to

be 9 inches in thickness, and well rammed into its position behind the brickwork.

The contractor is to provide, as part of this contract, all carriage, labour, materials, tools, pumping apparatus, or other means of lifting the water during the execution of works, and any other apparatus necessary for the due and proper execution of this contract.

A hand windlass of elm-wood, with substantial standards and frame, is to be provided and fixed at the top of the well, after the sinking and other operations have been completed. A best Manilla rope, $2\frac{1}{2}$ inches in circumference, with swivel attachment, and a strong elm or oak bucket, holding not less than 3 gallons, are also to be provided as part of this contract.

The works are to be completed to the satisfaction of Mr. ——, within two months after the date of the signing of this contract.

Payments will be made weekly, at the rate of 80 per cent. of the total work executed.

Materials.

The bricks are to be of approved manufacture.

The cement-mortar is to be composed of one part of Portland cement, and three parts clean furnace ashes or sharp sand.

The cement concrete is to be composed of one part of Portland cement, one part of clean, sharp sand, and three parts of small broken stone.

The timber is to be of the best-seasoned elm, free from all imperfections.

All other materials are to be of the best of their respective kinds.

ESTIMATE FOR SINKING AND LINING A WELL 80 FEET DEEP AND 4 FEET 6 INCHES IN DIAMETER.

Cubic yards.		At per cubic yard.				
		s.	d.	£	s.	d.
	Excavation.					
$9\frac{3}{4}$	Alluvium, sand and gravel	1	9		17	1
23	Soft marl	4	6	5	3	6
$52\frac{1}{4}$	Hard marl...	6	6	16	19	7
$5\frac{3}{4}$	Sandstone	10	0	2	17	6
	Brickwork.					
32	Brickwork in cement ...	40	0	64	0	0
	Concrete.					
$11\frac{3}{4}$	Portland cement concrete	16	0	9	8	0
	Miscellaneous.					
	Elm windlass, frame, bucket and rope complete			3	1	6
	Wooden cover-doors ...			0	6	6
	Removing excavation to spoil			4	10	0
	Lifting water			5	0	0
				112	3	8

LEAD POISONING.

Constant reference has been made in the course of these pages to the solvent properties which water sometimes possesses with regard to lead. This subject was forced upon public attention a few years ago, on account of its serious consequences at Sheffield and other northern towns, where the water is very soft in character, and is principally derived from moorland. These alarming outbreaks led to much careful investigation both as regards the peculiar constituents of such waters as are most liable to become polluted with salts of lead, as well as the circumstances which tend to facilitate such pollution.

Lead is a cumulative poison, and if water containing the most minute quantities is constantly employed for dietetic purposes, lead poisoning (plumbism or saturnism) must eventually supervene. The absorption of lead into the system constitutes a predisposing cause of many diseases, and there is a liability of symptomatic treatment, the true origin of the disorder being undiscovered. In fact, the theory has been propounded that nearly all cases of gout, Bright's disease (nephritis), and many other diseases, might be traced to lead poisoning.

There is perhaps no subject upon which more diversity of opinion exists amongst scientists than that which relates, firstly to the essential characteristics of the water itself, and secondly, to the most favourable conditions under which water will attack lead. With regard to the activity of the water there are several theories :—

1. Presence of acidity in the water.
2. Insufficiency of dissolved silica.
3. Absence of a sufficient proportion of dissolved carbonic acid (CO_2).
4. Deficiency of salts, especially of phosphates, carbonates, and sulphates.
5. Presence of sewage matter, especially of nitrates and nitrites.

1. *Presence of Acidity in the Water.*

There is no doubt that certain waters, especially from moorland sources, possess a distinct acidity, and that their lead-dissolving properties are directly proportional to their degree of acidity. This was shown to be the case by the experiments conducted by Dr. Sinclair White in connection with the Sheffield outbreak, and communicated in a paper read at the meeting of the British Medical Association, in Leeds, in August, 1889.

The nature of this acid is, we believe, yet a mystery. One opinion is that it consists of sulphuric acid, derived from the oxidation of iron pyrites; another opinion is that the

acid is of vegetable origin, and is due to the decomposition of vegetable matter (*e.g.* peat), possibly due to the action of bacteria.

The remedies proposed in this case are—

(*a*) Contact with fragments of limestone.

(*b*) Admixture of a proportion of milk of lime.

(*c*) Admixture of a proportion of carbonate of soda.

Contact with fragments of limestone, in addition to the admixture with the water of a certain quantity of quicklime, has been adopted with satisfactory results at Keighley. As the acidity of the water varies from time to time, the quantity of alkali necessary should be periodically determined by analysis, and added to the water in the form of powder or as milk of lime. This is the more important as it has been proved that an excess of lime increases the activity of water towards lead. Dr. Tidy is reported to have said that the beneficial action of limestone was due simply to the silica which it contained. Fragments of limestone become coated after a few weeks and require renewal; brushing is said to be effective.

The admixture of a proportion of carbonate of soda with the water has been strongly advocated by Dr. Percy F. Frankland (Sanitary Institute Congress, Brighton, 1890). The quantity to be used must be determined from time to time by analysis, 5 parts of carbonate of soda to 100,000 parts of water being an extreme case. This process has been adopted at Wakefield.

2. *Insufficiency of Dissolved Silica.*

This opinion has been strongly advocated by Dr. Tidy and other eminent chemists, as the result of observations which appeared to show that the activity of a water towards lead was destroyed when it contained upwards of half a grain of silica per gallon. It would seem, however, that this is not invariably the case, from the following instances:—

(*a*) Water from the Punch Bowl, Hindhead, which

contains 0·831 grains of silica per gallon, is said to act vigorously on lead.

(*b*) Experiments made by Professor Williams, of Sheffield, showed that silica added in definite quantities to an acid water did not diminish its solvent action upon lead.

(*c*) The High Level water at Sheffield acted vigorously upon lead whilst containing a larger proportion of silica than the Low Level water, which acted slightly or not at all upon lead.

Besides this, Dr. Sinclair White (1889) is of opinion that "the amount of silica which moorland water will take up from flints, even after long contact, is very small, and in practice it would seem to be exceedingly difficult, if not impossible, to silicate by means of ordinary flints some of these waters to the extent of containing half a grain per gallon. Mr. A. H. Allen has never succeeded in adding more than a quarter of a grain per gallon in this way, and Professor Percy Frankland's experience is of a similar character."

3. *Absence of a Sufficient Proportion of Dissolved Carbonic Acid* (CO_2).

This is tantamount to saying that a water should possess a certain degree of temporary hardness, and this theory is borne out by Dr. Percy Frankland, who states that such waters "may be generally considered above suspicion."

4. *Deficiency of Salts, especially of Phosphates, Carbonates, and Sulphates.*

In other words, soft waters are dangerous, and perhaps this is the most popular opinion upon the subject. It must be remembered, however, as already stated, that an *excess* of lime in a water tends to increase its activity towards lead; and that hard waters, which derive their salts from sewage-polluted sources (nitrates, nitrites, etc.), are especially active towards lead.

5. *Presence of Sewage-matter, especially of Nitrates, and Nitrites.*

Although this condition of a water undoubtedly renders it more active towards lead, it is almost needless to say that such pollution is not an indispensable cause.

It would appear that much time has been wasted in attempting to trace the property possessed by certain waters of attacking lead to one final cause, instead of admitting that many causes may be at work at the same time, either separately or conjointly.

With regard to the most favourable conditions under which water will attack lead, there is nearly as much variety of opinion.

A frequently stated dogma is that new lead only is to be feared, old lead becoming protected by a coating of carbonate of lead which forms upon its surface. Dr. Frankland has, however, shown that some waters act more and more upon pipes from day to day. It was originally believed that carbonate and sulphate of lead were insoluble in water; this was due to an error in the method adopted for analysis, which assumed that sulphide of lead was insoluble in water charged with sulphuretted hydrogen. Again, it has been shown that the coating of carbonate of lime and lead, which forms on a lead surface exposed to an active water, is pervious and does not act as a protection. This coating also is very liable to scale off as a result of vibration, *e.g.* in pipes, the opening and closing of taps, the passage of vehicles, change of temperature, etc.

The influence of pressure upon the action of the water has also led to much diversity of opinion. Dr. Sinclair White states, as the result of experiment, that, "Other things being equal, the greater the pressure under which the water is stored the greater amount of lead is taken up. This influence is considerable, but no amount of pressure will, of itself, render a harmless water active towards lead."

There is more agreement upon the influence of temperature,

and Dr. Sinclair White's statement that, "Other things being equal, an increase in the temperature of the water increases its lead-dissolving power," may be taken as the general opinion. This point, taken in connection with the remarks made above upon "temporary hardness," is interesting.

It seems to be generally accepted that lead surfaces exposed alternately to the action of air and water are more liable to be attacked; also that water becomes more active by becoming charged with air.

Where the water is acidulated its action is much increased when it can bring into circuit with the lead surfaces of iron, copper, zinc, brass, etc.; in such cases an electric current appears to be set up, the lead being the soluble electrode.

The importance of investigating the action of a proposed water-supply upon lead must be impressed upon the student. It must be borne in mind, in conducting this investigation, that the quality of a water from the same source varies considerably in this respect, and that all the conditions capable of affecting the question must therefore be carefully ascertained.

When, however, the active property of the water towards lead has been discovered subsequently to the construction of the works, in addition to the best practical measures being taken by the authority to counteract the solvent property before the water leaves their reservoir, information (in the form of leaflets) should be distributed amongst the consumers, so as to enable them to take such protective measures as will minimize the danger. The following recommendations have been suggested by Dr. Frankland:—

(1) That no water should be collected for drinking purposes until after the tap has been allowed to run for such a length of time as will presumably clear the service-pipe, and that drinking or cooking water may, therefore, be advantageously collected immediately after a considerable quantity of water has been drawn for other domestic purposes.

(2) That the filtration of the water through any form of animal charcoal filter, practically guarantees its absolute freedom from lead.

(3) That hot water acts more powerfully on lead than cold, and that, therefore, metal tea-pots and other soldered vessels for holding hot water should be avoided as much as possible.

It is an interesting fact, not yet satisfactorily explained, that filters composed of "animal charcoal" have the property not only of removing lead after it has been dissolved, but of removing from an active water its property of dissolving lead, and that this property is continuous.

Another point to be remembered is that the lead from which pipes are usually constructed is not chemically pure. They generally consist of two-thirds of new and one-third of old lead, the latter having been already used, and containing tin, zinc, antimony, and other metals, which facilitate the formation of electric currents.

CHAPTER XXVI.

PUBLIC INQUIRIES. CONCLUSION.

In the preliminary chapter it was stated that the money for carrying out waterworks by Local Authorities is usually obtained upon loan after a Local Government Board inquiry.

The Public Health Act, 1875, sec. 293, empowers the Local Government Board to cause to be made from time to time, "such inquiries as are directed by this Act, and such inquiries as they see fit in relation to any matters concerning the public health in any place, or any matter with respect to which their sanction, approval, or consent is required by this Act."

The principal matters connected with the supply of water to rural districts upon which public inquiries are held, are—

1. The borrowing of money beyond a certain amount.

2. The carrying of water-mains without the district.

3. The purchase of lands otherwise than by agreement.

4. The formation of a special drainage district for purposes of water supply.

5. The construction of large reservoirs.

The Public Health Act, 1875, sec. 295, states that "all orders made by the Local Government Board in pursuance of this Act shall be binding and conclusive in respect of the

matters to which they refer, and shall be published in such manner as the Board may direct."

Sec. 296 empowers inspectors of the Local Government Board "for the purposes of any inquiry directed by the Board (to) have in relation to witnesses and their examination, the production of papers and accounts, and the inspection of places and matters required to be inspected, similar powers to those which Poor Law Inspectors have under the Acts relating to the relief of the poor for the purposes of those Acts."

1. The Borrowing of Money.

By secs. 233, 234, Local Authorities are empowered, with the sanction of the Local Government Board, to borrow money for "permanent works" (*e.g.* waterworks), and for such purpose they may "mortgage to the person by or on behalf of whom such sums are advanced, any funds or rates out of which they are authorized to defray expenses incurred by them in the execution of this Act." In the case of a Rural Authority the cost of providing a supply of water to any contributory place within the district (*e.g.* parish) is by sec. 229, a special expense, and only the rate or rates out of which such expenses are payable may be mortgaged for that purpose.

The total amount of the loans outstanding is not at any time to exceed the "assessable" value for two years of the premises assessable within the district in respect of which such money may be borrowed. By "assessable" must be understood "rateable" in this connection.

Where the sum proposed to be borrowed, together with the balances of outstanding loans (if any), would exceed the assessable value for one year of such premises, the Local Government Board shall not give their sanction to such loan until one of their inspectors has held a local inquiry and reported to the said Board.

The loan is usually obtained from the "Public Works

Loan Commissioners," on the recommendation of the Local Government Board. It must be remembered that the Local Government Board can only recommend, and cannot compel.

2. The Carrying of Water-mains without the District.

Sec. 32 requires a Local Authority, before commencing the construction or extension (sec. 54) of any water-main without the district, to give three months' notice by advertisement in one or more of the local newspapers circulated within the district where the work is to be made. Such notice is to describe the nature of the intended work, and shall state the intended termini thereof, and the names of the parishes, and the turnpike roads and streets, and other lands (if any), through, across, under, or on which the work is to be made, and shall name a place where a plan of the intended work is open for inspection at all reasonable hours; and a copy of such notice shall be served on the owners or reputed owners, lessees or reputed lessees, and occupiers of the said lands, and on the overseers of such parishes, and on the trustees, surveyors of highways, or other persons having the care of such roads or streets.

Sec. 33 is to the effect that if any objection is raised against the intended works the said works must not be commenced without the sanction of the Local Government Board.

Sec. 34. "The Local Government Board may, on application of the Local Authority, appoint an inspector to make inquiry on the spot into the propriety of the intended work and into the objections thereto, and to report to the Local Government Board on the matters with respect to which such inquiry was directed, and on receiving the report of such inspector the Local Government Board may make an order disallowing or allowing, with such modifications (if any) as they may deem necessary, the intended work."

Sec. 285 provides that "any Local Authority may, with the consent of the Local Authority of any adjoining district, execute and do in such adjoining district all or any of such works and things as they may execute and do within their own district, and on such terms as to payment or otherwise as may be agreed on between them and the Local Authority of the adjoining district."

An important issue has arisen in connection with the two last clauses, which is clearly set forth in the following extract from the *Justice of the Peace* for May 19, 1894, which applies equally to water-mains (sec. 54):—

"Query: (2) If one authority desires to carry a sewer through land of an adjoining authority, will it be sufficient to comply with sec. 32, or will it be necessary to obtain the consent mentioned in sec. 285?

"(3) If such consent is necessary, can it be arbitrarily withheld by the adjoining authority?

"Answer: (2) We think the consent of the adjoining authority must be obtained. Such consent is a condition precedent to the works being undertaken.

"(3) If the consent is withheld, there is no power of compelling the consent to be given. It is, therefore, immaterial whether or not the consent is arbitrarily withheld, as such consent is necessary before undertaking the works."

3. The Purchase of Land otherwise than by Agreement.

A Local Authority, after having complied with the requirements of sec. 176 (sub-sec. 2), with regard to publication and the service of notices, may petition the Local Government Board to permit them to put into force the Land Clauses Consolidation Acts. After receiving such petition, and being satisfied that the necessary formalities as to publication and service of notices have been complied with, the Local Government Board may either dismiss the

petition or institute an inquiry. After such inquiry the Local Governmen Board may grant the petition, with such modifications or conditions that the Board may think fit.

4. The Formation of Special Drainage Districts.

As stated in Chapter I., the Local Government Board are rarely in favour of this step for purposes of water supply alone.

5. The Construction of Large Reservoirs.

This refers only to reservoirs other than service-reservoirs or tanks which will hold not more than 100,000 gallons, and therefore rarely applies to questions of rural water-supply. The Local Authority is required to properly advertise the proposed work in the local newspapers, and if any person who would be affected by the intended work lodges an objection, the Local Authority may appeal to the Local Government Board. After receiving such appeal the Local Government Board may institute an inquiry, after which they may make an order disallowing or allowing, with such modifications (if any), as they may deem necessary, the intended work.

Where a Local Authority make default (*inter alia*), in providing their district with a supply of water (sec. 299), and complaint is made to the Local Government Board, the Local Government Board, "if satisfied, after due inquiry, that the authority has been guilty of the alleged default, shall make an order limiting a time for the performance of their duty in the matter of such complaint. If such duty is not performed by the time limited in the order, such order may be enforced by writ of mandamus, or the Local Government Board may appoint some person to perform such duty." Similar powers are now given by the Local Government Act, 1894 (sec. 16), to County Councils upon the complaint of Parish Councils.

Before holding an inquiry, the Local Government Board require to be supplied with certain information in the form of statistics, plans, estimates, and details. The requirements of the Local Government Board as to plans have already been dealt with in Chap. XI. The remaining information has to be supplied upon forms issued for the purpose by the Local Government Board, which are filled up by the clerk or engineer, according to the nature of the queries.

The appended form has to be filled up by the engineer of the proposed works—

Works of Water Supply.

Estimates and Details.

Name of Sanitary Authority ——.

In the case of a Rural Sanitary Authority, name of contributory place for which the works are required ——.

ESTIMATE FOR CAST-IRON MAINS.

Name of street or road.	Internal diameter of pipes in inches.	Weight per yard.	Total length in yards.	Total weight.	To carry head in feet vertical.	To carry lbs. pressure on the inch.	Price per cwt.	Total.
		cwts. lbs.		cwts. lbs.				£ s. d.

Estimate for Fittings.

Description of Work.	Nos.	Internal diameter in inches of valves, etc.	Weight of each in cwts. and lbs.	Price for cash complete.	Total.	Remarks.
					£ s. d.	
Fire-cocks and hydrants						
Casings to fire-cocks and hydrants complete						
Sluice-valves						
Casings to sluice-valves complete						

N.B.—Describe the sluice-valves, fire-cocks and hydrants, and state if or not the valves, or any portion of them, are to be of gun-metal.

Describe the casings and street fittings in detail.

Furnish diagrams if they have been prepared.

DETAILS OF THE WORKS.

Headings for a Detailed Description of the Works to be furnished by the Engineer.

Pumping Works.

1. Sort of engine proposed.
2. Estimated power of engine.
3. Estimated weight of coal per hour, per horse-power.
4. Volume of water to be lifted.
5. Head to which water is to be lifted.

6. Internal diameter of rising-main, in inches.

7. Calculated velocity of water in feet per second, through the rising-main.

Impounding and Storage Reservoir.

1. Area of gathering ground, in acres.
2. Average annual depth of rainfall.
3. Surface area of reservoir when full, in acres.
4. Greatest depth of water in the reservoir when full, in feet.
5. Total volume when full, in gallons.
6. Length of bye-wash.
7. Height of the embankment above top water-level, and top width and thickness of the puddle-wall at bottom and at top.

Covered Service Reservoir.

1. Area of reservoir in square yards.
2. Depth of water in reservoir when full, in feet.
3. Volume of water in reservoir when full, in gallons.

N.B.—Describe in writing the proposed mode of construction of covered reservoirs; as, also, how the reservoir is to be ventilated, lighted, and worked.

It is not desirable to make the pumping main a supply main also, nor should the velocity through any pumping main exceed 2 feet per second.

The whole of the cast-iron pipes and other castings must be varnished.

There should not be less than 3 feet in length of bye-wash for each 100 acres of gathering ground.

Add any additional details necessary to a full explanation of the proposed works.

Plans and sections, or tracings of them, together with details, must be furnished.

SUMMARY.

Description of work.	Cost.	Total cost.	Remarks.
	£ s. d.	£ s. d.	

Date—— Signed——

N.B.—This form should be signed by the engineer of the proposed works.

At the inquiry the engineer is called upon to describe and explain the proposed works, and is frequently subjected to a sharp cross-examination upon the details. It is therefore necessary that he should be fully prepared upon every point, and have his notes in such a form as to be ready for reference at a moment's notice. A useful method is to use a note-book with an alphabetical margin, and to arrange the various matters alphabetically. This practice will be found simple and rapid. Another useful practice is to lay down the mains and branches upon a 1-inch Ordnance map indicating the positions of reservoirs, tanks, sluice-valves, hydrants, etc., and distinguishing by means of different colours the ownership of all lands built upon, passed through, or in any way affected by the intended works.

In conclusion we would urge upon the student the necessity for careful thought and preparation before advancing any scheme for water supply. The details comprehended in the profession of a waterworks engineer are innumerable, but upon the full appreciation of these details will depend his success or failure. A small scheme requires, in its way, as much preparation as a large one, and an error in calculation,

which in the latter would be insignificant, might be the ruin of the former.

The habits of careful investigation, unerring accuracy, and steady perseverance, combined with a thorough practical knowledge, are qualifications which alone will lead to the execution of those works with which the engineer may afterwards be proud to hear his name associated.

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THE END.

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